Draft Report

# SECOND PROSPECTIVE ANALYSIS OF AIR QUALITY IN THE U.S.: AIR QUALITY MODELING

08-099

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# Section I
# Introduction

Section 812 of the Clean Air Act Amendments (CAAA) of 1990 requires the U.S. Environmental Protection Agency (EPA) to periodically assess the effects of the Clean Air Act (CAA) on air quality, the environment, public health, and the economy. This type of analysis requires the estimation of future-year emissions levels and associated air quality related values for scenarios reflecting compliance with the CAA, as well as scenarios that do not account for the effects of programs associated with the CAA in establishing the future-year estimates.

Prior retrospective and prospective analyses of the benefits and costs of the CAA conducted by EPA have used a variety of air quality modeling and analysis methods to estimate the effects of implementing the CAA measures on future-year ambient air quality. This report summarizes the methods and results of the emissions processing and air quality modeling that were conducted to support the development of the second prospective CAA Section 812 benefit-cost study.

This analysis is the first Section 812 prospective analysis to use an integrated modeling system, the Community Multiscale Air Quality (CMAQ) model, to simulate national and regional-scale pollutant concentrations and deposition. The CMAQ model (Byun and Ching, 1999) is a state-of-the-science, regional air quality modeling system that is designed to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere.

The CMAQ model was applied for seven core CAAA scenarios that include four different years that span a 30-year period – 1990, 2000, 2010 and 2020. Scenarios that incorporate the emission reductions associated with the CAA are referred to as with-CAAA while those that do not are referred to as without-CAAA. The scenarios include:

Retrospective Base-Year Scenario
1990 without-CAAA

Base- and Future-Year Scenarios without 1990 CAAA Controls
2000 without-CAAA
2010 without-CAAA
2020 without-CAAA

Base- and Future-Year Scenarios with 1990 CAAA Controls
2000 with-CAAA
2010 with-CAAA
2020 with-CAAA

An integral component of the modeling analysis is the estimation of future-year emissions for the seven core scenarios. The emissions estimates were prepared by EPA and are discussed in some detail by Wilson et al. (2008). Emissions for the historical years (1990 and 2000) were based on the best available emission inventories for these years. Projection to the future years was based on economic growth projections, future-year control requirements (for attainment of National Ambient Air Quality Standards (NAAQS)), and control efficiencies. Different assumptions were applied for the with- and without-CAAA scenarios resulting in a different future-year emissions pathway for each scenario. The emissions data were processed for input to the CMAQ modeling using the Sparse-Matrix Operator Kernel Emissions (SMOKE) emissions processing system (CEP, 2004).

The model-ready emission inventories for each scenario and year were then used to obtain base- and future-year estimates of the key criteria pollutants, as well as many other species. The air quality modeling analysis was designed to make use of tools and databases that have recently been developed and evaluated by EPA for other national- and regional-scale air quality modeling studies. In particular, model-ready meteorological input files for 2002 were provided by EPA for use in this study. For fine particulate matter ($PM_{2.5}$) and related species, the CMAQ model was applied for an annual simulation period (January through December). A 36-km resolution modeling domain that encompasses the contiguous 48 states was used for the annual modeling. For ozone and related species, the CMAQ model was applied for a five-month simulation period that captures the key ozone-season months of May through September. Two 12-km resolution modeling domains (that when combined cover the contiguous 48 U.S. states) were used for the ozone-season modeling. Altogether, model-ready emission inventories were prepared and the CMAQ model was applied for a total of 21 simulations (comprising seven core scenarios and three modeling domains).

The outputs from the CMAQ model provide the basis for the calculation of health and ecological benefits of the CAA. The airborne criteria pollutants of interest include ozone and fine particulate matter ($PM_{2.5}$), where $PM_{2.5}$ consists of particles less 2.5 microns in diameter. Visibility is also an air quality parameter of interest and this was calculated using a variety of the CMAQ output species. In addition, deposition of nitrogen and sulfur was also extracted from the model outputs.

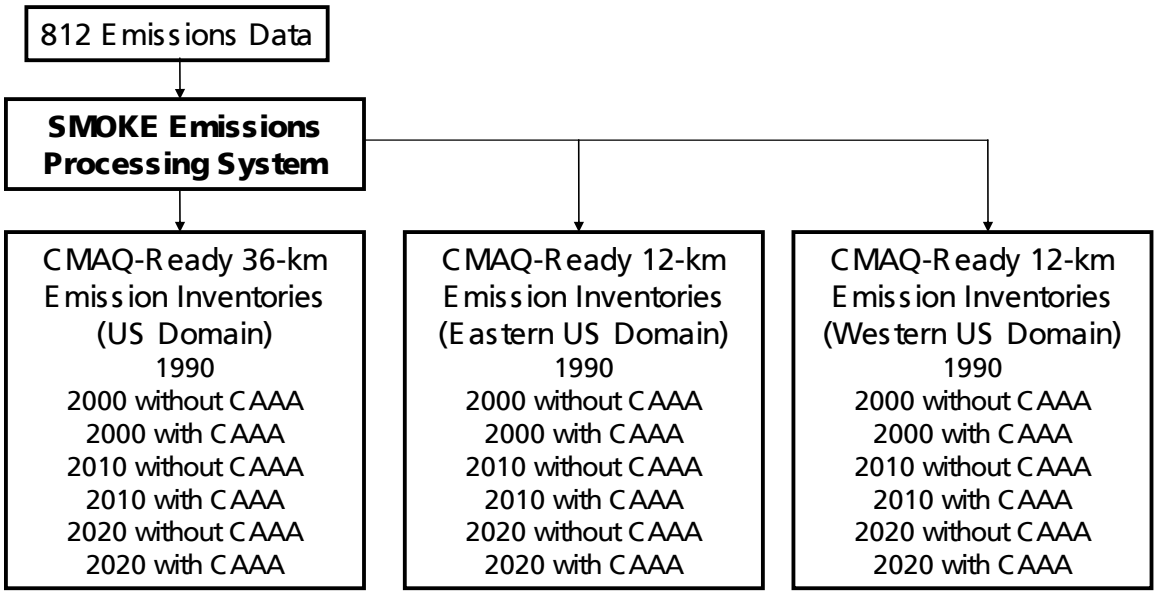
The remainder of this report summarizes the methods and results of the second Section 812 prospective air quality modeling analysis. An overview of the air quality modeling methodology is provided in Section 2. The emissions processing is summarized in Section 3. The air quality modeling methods and results are presented in Section 4. A discussion of the attributes and limitations of the modeling analysis methodologies is provided in Section 5. Finally, recommendations for further research are given in Section 6.

# Section II
# Overview of the Air Quality Modeling Methodology

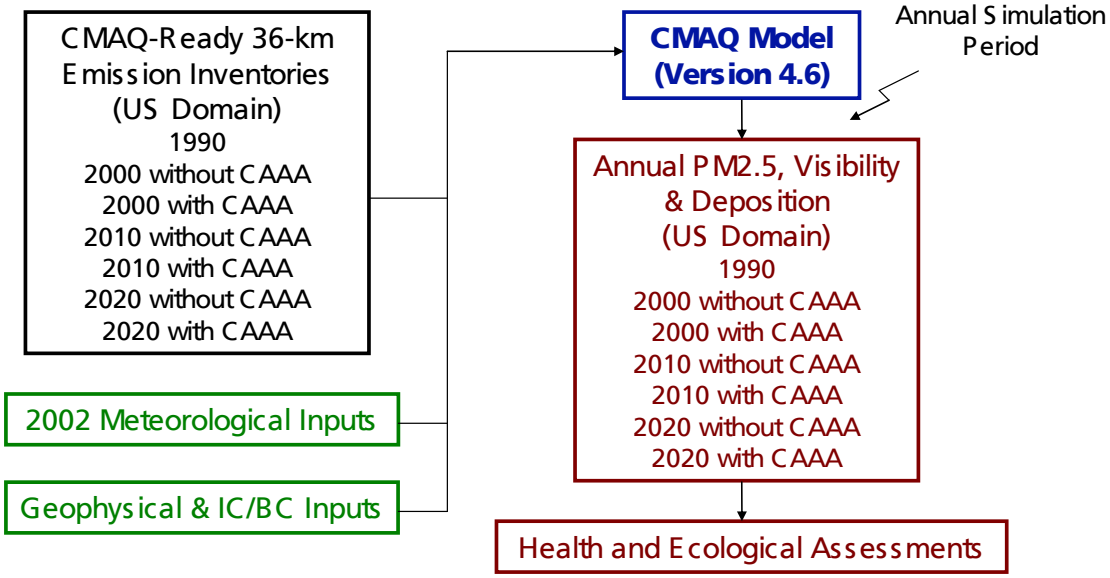
The air quality modeling component of the Section 812 prospective analysis included the application of the SMOKE emissions processing software, the CMAQ air quality model, and several post-processing and analysis tools. In addition, the modeling analysis included the use of detailed emissions data for each year and scenario and meteorological, geophysical and other inputs representative of 2002. Three separate modeling domains were employed. The input files, simulation period, and modeling domains are discussed in more detail in Sections III and IV. An overview of the modeling approach is provided in Figure II-1.

**Figure II-1. Schematic Diagram of Section 812 Air Quality Modeling Analysis.**

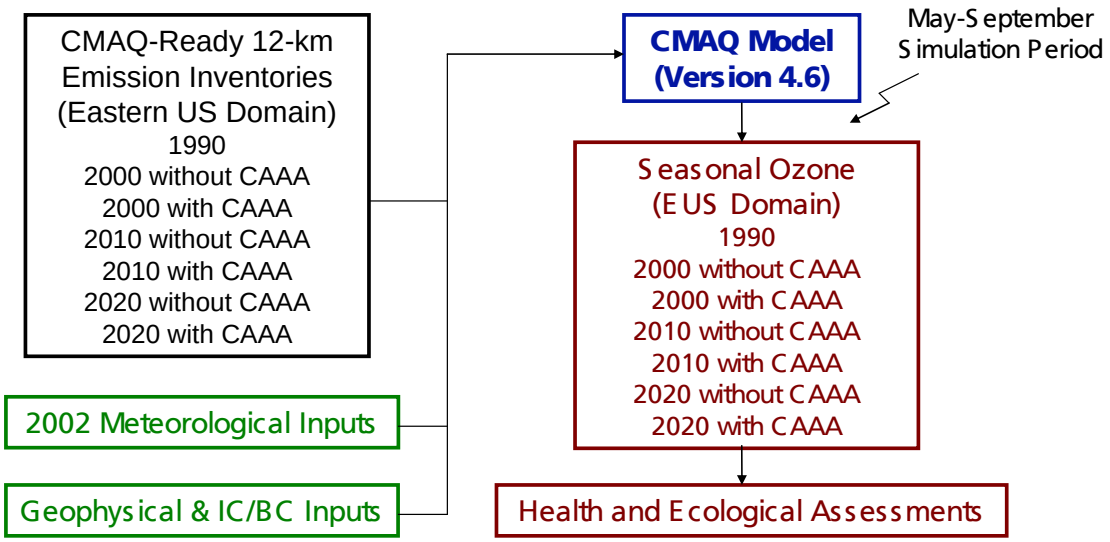
*(a) SMOKE Emissions Processing Component*



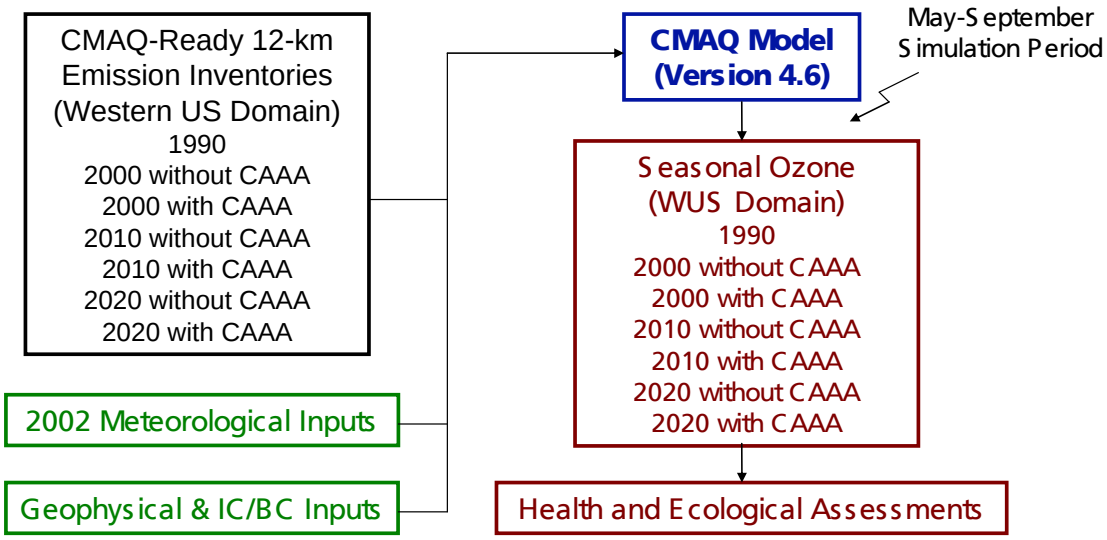
*(b) CMAQ Application for the 36-km Continental U.S. (CONUS) Domain.*




*(c) CMAQ Application for the 12-km Eastern U.S. (EUS) Domain.*



*(d) CMAQ Application for the 12-km Western U.S. (WUS) Domain.*



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# Section III
# Emission Inventory Preparation

## Introduction

This section summarizes the data, methods, and procedures followed in preparing modeling emission inventories for the air quality modeling analysis conducted for the second 812 prospective study. The major objective of the 812 prospective study is to evaluate the costs and benefits of emission reductions mandated by the 1990 Clean Air Act Amendments (CAAA). The first part of the analysis involves the preparation of national criteria pollutant emission inventories that include: 1) a base year inventory for 1990 to establish the emissions baseline prior to any CAAA-mandated controls, 2) an interim year inventory for 2000 that includes some CAAA controls, and 3) two future-year inventories (2010 and 2020) that include expected future controls. The second part of the analysis, the results of which are summarized in the following sections of this report, includes a series of air quality modeling simulations that are performed to evaluate the expected changes in air quality for the years 2000, 2010, and 2020 using emission inventories that include and exclude (with and without) the CAAA controls. The results of these simulations provide estimates of the benefits to air quality throughout the US for ozone and particulate matter as a result of the emissions reductions realized (or expected to be realized) from controls and other air quality management programs as a result of the CAAA. To complete the overall Section 812 benefit-cost analysis, this third part of the analysis (to be conducted by others) also involves an evaluation of the incremental costs of control programs associated with the CAAA.

## Emissions Data and Methods

For the 812 air quality modeling analysis, EPA's Community Multiscale Air Quality (CMAQ) model (Version 4.6), containing the Carbon Bond 2005 (CB-05) chemical mechanism, was utilized. The CMAQ model requires as input hourly, gridded emissions of both anthropogenic and biogenic sources that have been spatially allocated to the appropriate grid cells and chemically speciated for the applicable chemical mechanism used in the model. The emissions inventories prepared for the modeling analysis were based on information originally developed and provided by EPA and its emissions contractors, E. H. Pechan & Associates and Industrial Economics, Inc. The details of the development of the 1990 and 2000 base case and 2010 and 2020 future year inventories are contained in two recent publications (Wilson, et al., 2008 and E. H. Pechan & Industrial Economics, Inc., 2006). Input information was provided for the 48 states of the US and portions of Canada and Mexico. Using the emissions inputs provided, the modeling inventories were processed and prepared for CMAQ using EPA's Sparse-Matrix Operator Kernel Emissions (SMOKE) software (Version 2.3.2) for the following pollutants: volatile organic compounds (VOC), oxides of nitrogen ($NO_x$), carbon monoxide (CO), sulfur dioxide ($SO_2$), fine particulates ($PM_{2.5}$), coarse particulates ($PM_{10}$), and ammonia ($NH_3$). Information provided by EPA for preparation of the base and future-year modeling inventories included SMOKE input and output files for area, non-road, on-road, EGU and non-EGU sectors, and "identified" and "unidentified" local control information by county and source category code for each pollutant.

As noted, modeling inventories for the following emissions scenarios were developed for the 812 prospective analysis:

| | |
|---|---|
| 1990 Base Case | 2000 with-CAAA (Base Case) |
| 2000 without-CAAA | 2010 with-CAAA |
| 2010 without-CAAA | 2020 with-CAAA |
| 2020 without-CAAA | |

The 1990 base case serves as the basis for the development of all subsequent inventories without CAAA controls, while the 2000 with-CAAA scenario serves as the basis for the development of the 2010 and 2010 with-CAAA inventories. The inventories that include controls represent provisions contained in the following sections of the 1990 CAAA:

- Title I VOC and $NO_x$ reasonably available control technology (RACT) requirements in ozone nonattainment areas (NAAs);
- Title II on-road motor vehicle and non-road engine/vehicle provisions;
- Title III National Emissions Standards for Hazardous Air Pollutants (NESHAPS), and
- Title IV emissions programs for EGUs, as estimated by the Integrated Planning Model (IPM)

As presented in Wilson et al., (2008), Table III-1 summarizes the origin of the information by source category of the inventories that comprise the base case scenarios for 1990 and 2000, from which the other inventories were derived.

**Table III-1. Base year Emission Data Sources for the With- and Without-CAAA Scenarios.**

| Sector | Without-CAAA Scenario 1990 | With-CAAA Scenario 2000 |
|---|---|---|
| EGU | 1990 EPA point-source NEI | Estimated by EPA IPM for 2001 |
| Non-EGU Point | 1990 EPA point-source NEI | 2002 EPA point-source NEI (final version 2.0) |
| Non-point | 1990 EPA non-point-source NEI with adjustments for priority source categories. | 2002 EPA point-source NEI (final version 1) |
| On-road | Mobile 6.2 emission factors and 1990 NEI VMT database | MOBILE 6.2 emission factors and 2000 NEI VMT database. CARB supplied estimates for California |
| Off-road/ non-road | NON-ROAD 2004 model simulation for calendar year 1990 | NON-ROAD 2004 model simulation for calendar year 2000 |

*Source: Wilson et al., 2008*

As noted, the on-road and non-road inventories were developed using consistent emissions processors (MOBILE6.2 and NON-ROAD2004) along with year-specific VMT and equipment/activity databases corresponding to 1990 and 2000. The EGU inventories were developed for 1990 from the 1990 National Emission Inventory (NEI) and for 2000 using the Integrated Planning Model (IPM). The future-year inventories were developed for two scenarios: a)

without-CAAA: includes expected growth in population and activity, but no controls beyond those in place in 1990, and b) with-CAAA: includes expected growth in population and activity and reflects controls mandated in the 1990 CAAA. In developing the future-year inventories, growth in emissions or activity was applied for the future year and then applicable controls were applied.

Table III-2 summarizes the approach followed in estimating the future year emissions for the Section 812 prospective analysis. In developing the future year inventories, the emissions for Mexico were left at base year levels. The controls on non-EGU point and non-point (area) sources were developed for their respective areas by the five Regional Planning Organizations (RPOs) that have been conducting modeling and analyses for regional haze, visibility, and $PM_{2.5}$ assessments in recent years throughout the US. These RPOs include the Visibility Improvement State and Tribal Association of the Southeast (VISTAS), the Mid-Atlantic and Northeast Visibility Union (MANE-VU), the Midwest Regional Planning Organization (MWRPO), the Central Regional Planning Association (CENRAP), and the Western Regional Air Partnership (WRAP).

**Table III-2. Approach for Estimating Future-Year Emissions.**

| Sector | Growth Forecast | Estimation of Controls |
|---|---|---|
| EGU | DOE AEO 2005 forecasts | IPM |
| Non-EGU Point | DOE AEO 2005 forecasts | On the basis of control factors developed by the five RPOs and California from CARB |
| Non-point | DOE AEO 2005 forecasts | On the basis of control factors developed by the five RPOs and California from CARB |
| On-road | National VMT forecast from AEO 2005 | MOBILE6.2 emission factors |
| Off-road/ non-road | EPA NON-ROAD 2004 model growth forecasts are largely based on historical trends in national engine populations by category/subcategory of engine | NON-ROAD2004 model |

*Source: Wilson et al., 2008*

The without-CAAA inventories for 2000, 2010, and 2020 contain expected growth in various source sectors, with RACT controls held at 1990 levels for non-EGU point sources; RACT, New Source Review (NSR), Prevention of Significant Deterioration (PSD), and New Source Performance Standards (NSPS) held at 1990 levels for EGUs; engine standards held at 1990 levels for non-road engines/vehicles; engine standards, Phase I Reid Vapor Pressure (RVP) limits, and Inspection and Maintenance (I/M) programs set prior to/in place by 1990 assumed for on-road motor vehicles; and controls held at 1990 levels for area/non-point sources.

The with-CAAA inventories for 2000, 2010, and 2020 contain provisions mandated by the CAAA, including for non-EGU point sources such provisions as $NO_x$ and VOC RACT for all nonattainment areas (NAAs), new control technique guidelines (CTGs), and applicable Maximum Achievable Control Technology (MACT) for VOCs; for EGUs, among other things, applicable RACT, NSR, PSD, and NSPS requirements, the Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR) provisions, and other measures to meet PM and ozone NAAQS; for non-road engines such controls as the Federal locomotive, commercial/recreational marine vessel standards, Phase I and II engine standards, Non-road Diesel Rule, and gasoline sulfur limits; for

on-road motor vehicles, Tier I & II tailpipe standards, a 49-state Low Emission Vehicle (LEV) program, I/M programs for ozone NAAs, Federal Reformulated Gas (RFG) for certain NAAs, Phase 2 RVP limits, California LEV and RFG, and diesel fuel sulfur limits, among other provisions; and for non-point/area sources such provisions as RACT, new CTGs, Stage II vapor recovery, and other measures to meet PM and ozone NAAQS, including those contained in various Early Action Compacts.

The national, regional, and local controls imposed in developing the with-CAAA inventories for 2010 and 2020 reflect those controls "on the books" as of September 2005. In addition to these controls, an analysis was conducted by Pechan to estimate additional local controls that reflect efforts and control requirements identified by state and local governments to achieve applicable NAAQS for ozone and $PM_{2.5,}$ and provisions included in EPA's recent Clean Air Visibility Rule (CAVR), also referred to as the BART rule. The assessment of potential control measures was conducted using EPA's AirControlNET model, which provides a linkage between identified control technologies/measures and EPA emission inventories. For certain NAAs that will require more rigorous controls, the local control measures assessment included reductions associated with unidentified measures, which were included in the future-year modeling inventories.

## Emissions Processing Procedures

As noted above, the SMOKE emissions processor (Version 2.3.2) was utilized to process the emissions and prepare CMAQ-ready inputs for the various scenarios using source sector files provided by EPA and Pechan. The preparation of the various inventories included a) processing using various SMOKE programs, b) the application of control factors to emulate identified and unidentified controls at the local level for various nonattainment areas, and c) review and quality assurance checks. In addition, in processing the modeling emission inventories, a number of revisions were made to the original files provided by EPA and Pechan, as detailed below.

The general procedures followed in preparing the modeling inventories, using various programs included with SMOKE, are the following:

- Apply local control to emissions inventory data files (for with-CAAA inventories only)
- Perform chemical speciation to transform input criteria pollutants into the Carbon Bond 2005 (CB-05) chemical mechanism species, as required by CMAQ
- Perform temporal distribution to distribute the input annual/monthly emissions into hourly emissions
- Perform spatial distribution of input emissions to the various modeling grids
- Merge emissions from EGU, non-EGU, non-point, non-road, on-road, and biogenic sectors into the CMAQ model-ready files
- Conduct a review and quality assurance of the inventory processing

### Development and Application of Local Control Factors for 2010 and 2020

The emission inventory files developed by EPA and Pechan for the second prospective analysis reflect federal, state, and local provisions of what was "on the books" as of September 2005, but do not include additional local controls that are expected to be identified and in place in various nonattainment areas by 2010 and 2020 to address both 8-hr ozone and $PM_{2.5}$ nonattainment issues. To estimate the expected reductions in emissions for the 2010 and 2020 inventories resulting from these local controls, Pechan conducted an analysis using EPA's AirControlNET model, which links control technologies and pollution prevention measures to EPA inventories.

From this analysis, a set of control factors for "identified" controls was developed. For certain areas with more severe control requirements (beyond what could be estimated by AirControlNET), additional "unidentified" controls were developed by examining available future-year air quality modeling results and making estimates of what other local reductions would be required to meet the 8-hr ozone standard. The "unidentified" controls were developed for 27 nonattainment areas.

The following summarizes how the local controls were incorporated into the 2010 and 2020 with-CAAA inventories:

**Identified Local Controls**: EPA provided an Access database file that contained the percentage reduction estimates for area, non-road, on-road, EGU and non-EGU sectors for the 2010/2020 identified local control measures, by county and source category code, for each pollutant. This information was incorporated into the inventories as follows:

- The control factors for the 2010/2020 identified local control measures were calculated using the EPA provided database.
- The on-road emissions were provided by detailed source category codes in the SMOKE IDA files, and the percentage reductions for on-road emissions were provided by aggregated source category codes in the EPA database. The control factors for each aggregated source category were applied to all corresponding detailed source categories.
- The on-road exhaust and evaporate VOC emissions were provided separately in the SMOKE IDA files, and the percentage reductions for on-road emissions were provided for overall VOC in the EPA database. The overall VOC control factors were applied to both exhaust and evaporate VOC emissions.

**Unidentified Local Controls**: EPA provided an Access database file that contained the 2010/2020 residual emissions (the emissions remaining after the identified controls have been applied, but before the unidentified controls) for all counties and source categories, and the county FIPS codes within the NAA that the unidentified controls will be applied to. EPA also provided the total unidentified $NO_x$ and VOC emissions reduction for the NAA by county for area, on-road and non-road sectors.

The control factors for the unidentified control measures by county and source category code (SCC) were calculated as follows:

- Extract the residual emissions for the SCC in area, on-road and non-road sectors for the counties within the NAA from the EPA Access database.
- Calculate the residual emissions totals for area, on-road and non-road sectors for each county within the NAA.
- Compare the residual emissions and unidentified emissions reductions, and calculate the control factors for $NO_x$ and VOC by sector for each county within the NAA.
- Assign the control factors for area, non-road and on-road sectors by county and SCC for each NAA.

## Revisions Made to Emissions Input Files

After receiving the initial emission inventory files from EPA and Pechan, a number of revisions were made to various files prior to the development and processing of the modeling scenario inventories. These include the following, by source category:

**On-road Sources**

- Used older version of EPA PM2.5 speciation profiles and associated cross references to speciate PM2.5 emissions to accommodate the fact that the on-road PM2.5 emissions provided were not separated for tire dust, brake lining dust, gasoline exhaust, LDDV exhaust and HDDV exhaust.

**Non-road Sources**

- Used the older version of EPA VOC speciation profiles and associated cross reference files to speciated VOC emissions to accommodate the fact that the non-road emissions provided were not separated for exhaust, evaporative, and refueling emissions.

**Area Sources**

- Added 100 source category codes (SCC) to the SMOKE IDA file that are not included in the EPA's latest speciation profile cross reference file.

**Non-EGU Sources**

- Added 379 SCCs to the SMOKE IDA file that are not included in the EPA's latest speciation profile cross reference file.
- Added 35 SCCs to the SMOKE IDA file that are not included in the EPA latest temporal profile cross reference file.

## Quality Assurance Procedures

The emissions inventory processing quality assurance (QA) procedures included the development and examination of tabular emissions summaries and graphical display products.

Tabular summaries were prepared to examine emissions totals for various steps of the emissions processing. Summaries for input emissions are based on the input inventory data: monthly emissions for the on-road sector, and annual emissions for other sectors for criteria pollutants. Summaries for output emissions are based on the SMKMERGE reports: daily emissions for CB-05 species for each sector. The output daily emissions are summed over all days in the year and the CB-05 species are summed for the criteria pollutants. The emissions summaries were made for each scenario by state and sector, and comparisons were made between the input emissions and output emissions for each sector to assure consistency. Comparisons were also made between the base and future years for both the with- and without-CAAA scenarios.

In addition to the tabular summaries, various graphical displays were prepared for one day of each month to examine the spatial distribution and temporal variation for each sector and the final merged emissions using the PAVE graphical plotting package. In addition, difference plots were prepared comparing the with- and without-CAAA scenarios for the future years for one day of each month to show the spatial emissions changes due to the controls.

## Summary and Discussion of Modeling Emission Inventories

Using the inputs provided by EPA, the SMOKE emissions processing system was utilized to prepare the CMAQ model-ready hourly emission inventory inputs for each of the modeling scenarios for the 36-km resolution national grid (referred to as the CONUS grid), and the 12-km resolution Eastern U.S. (EUS) and Western U.S. (WUS) grids. Although the processed emission inventories were prepared for the full list of species listed above, most of the presentation and discussion that follows focuses on the VOC, $NO_x$, $SO_2$, and $PM_{2.5}$ emissions species.

Table III-3 presents national (48-state) emissions totals for each pollutant by sector for each of the 812 scenarios, and Table III-4 presents emission totals for all sectors combined. These estimates are very similar to those presented by Wilson (2008), with small differences attributed to changes/updates from the original inputs, differences due to processing with SMOKE, and potential differences due to the calculation involved in applying the local identified and unidentified controls.

**Table III-3. National (48-State) Emission Inventory Totals (thousand tons/yr) by Sector for the 812 Modeling Scenarios.**

| Pollutant | Sector | 1990 | 2000 Without-CAAA | 2000 With-CAAA | 2010 Without-CAAA | 2010 With-CAAA | 2020 Without-CAAA | 2020 With-CAAA |
|---|---|---|---|---|---|---|---|---|
| VOC | EGU | 36 | 40 | 41 | 43 | 43 | 48 | 47 |
| | Non-EGU Point | 2,609 | 3,078 | 1,402 | 3,463 | 1,434 | 3,999 | 1,646 |
| | Non-point | 11,280 | 12,427 | 8,544 | 13,601 | 8,277 | 15,703 | 9,009 |
| | Non-road | 2,666 | 3,218 | 2,565 | 4,077 | 1,831 | 4,753 | 1,427 |
| | On-road Vehicle | 9,328 | 5,857 | 5,232 | 5,734 | 2,533 | 6,767 | 1,573 |
| $NO_x$ | EGU | 6,571 | 7,736 | 4,495 | 8,352 | 2,301 | 8,689 | 1,885 |
| | Non-EGU Point | 3,133 | 3,331 | 2,292 | 3,556 | 1,991 | 3,997 | 2,011 |
| | Non-point | 4,952 | 4,832 | 3,886 | 5,014 | 3,577 | 5,198 | 3,494 |
| | Non-road | 2,068 | 2,191 | 2,091 | 2,665 | 1,588 | 3,162 | 928 |
| | On-road Vehicle | 9,536 | 8,759 | 8,052 | 9,106 | 4,182 | 10,667 | 1,758 |
| CO | EGU | 312 | 497 | 504 | 602 | 618 | 751 | 772 |
| | Non-EGU Point | 5,667 | 6,467 | 3,113 | 6,808 | 3,291 | 7,382 | 3,677 |
| | Non-point | 17,318 | 16,269 | 14,614 | 15,365 | 14,605 | 15,089 | 15,451 |
| | Non-road | 22,176 | 25,459 | 22,330 | 31,542 | 26,214 | 37,199 | 28,995 |
| | On-road Vehicle | 109,566 | 78,786 | 66,931 | 80,491 | 41,976 | 95,242 | 35,624 |
| $SO_2$ | EGU | 16,202 | 18,151 | 10,822 | 18,872 | 6,366 | 18,744 | 4,271 |
| | Non-EGU Point | 4,293 | 4,100 | 2,193 | 4,487 | 2,057 | 4,872 | 2,054 |
| | Non-point | 2,659 | 2,346 | 1,875 | 2,705 | 1,878 | 3,044 | 1,942 |
| | Non-road | 163 | 178 | 177 | 225 | 17 | 270 | 3 |
| | On-road Vehicle | 500 | 631 | 253 | 797 | 30 | 984 | 36 |

| Pollutant | Sector | 1990 | 2000 Without-CAAA | 2000 With-CAAA | 2010 Without-CAAA | 2010 With-CAAA | 2020 Without-CAAA | 2020 With-CAAA |
|---|---|---|---|---|---|---|---|---|
| $PM_{10}$ | EGU | 542 | 752 | 729 | 835 | 641 | 897 | 623 |
| | Non-EGU Point | 1,735 | 2,014 | 598 | 2,202 | 608 | 2,491 | 704 |
| | Non-point | 22,499 | 23,124 | 19,332 | 22,822 | 18,841 | 24,256 | 19,008 |
| | Non-road | 309 | 287 | 266 | 323 | 200 | 367 | 131 |
| | On-road Vehicle | 385 | 246 | 220 | 229 | 151 | 268 | 134 |
| $PM_{2.5}$ | EGU | 365 | 634 | 611 | 705 | 515 | 763 | 495 |
| | Non-EGU Point | 1,299 | 1,516 | 365 | 1,652 | 394 | 1,872 | 451 |
| | Non-point | 5,258 | 5,420 | 4,103 | 5,371 | 4,054 | 5,732 | 4,160 |
| | Non-road | 284 | 264 | 245 | 297 | 185 | 338 | 120 |
| | On-road Vehicle | 322 | 191 | 165 | 170 | 94 | 199 | 70 |
| $NH_3$ | EGU | 0 | 3 | 3 | 1 | 1 | 0 | 0 |
| | Non-EGU Point | 244 | 236 | 154 | 237 | 174 | 256 | 202 |
| | Non-point | 3,260 | 3,624 | 3,552 | 3,830 | 3,713 | 4,131 | 3,987 |
| | Non-road | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| | On-road Vehicle | 154 | 272 | 272 | 336 | 334 | 397 | 394 |

**Table III-4. National (48-State) Emission Inventory Totals (thousand tons/yr) for all Sectors Combined for the 812 Modeling Scenarios.**

| Pollutant | 1990 | 2000 Without-CAAA | 2000 With-CAAA | 2010 Without-CAAA | 2010 With-CAAA | 2020 Without-CAAA | 2020 With-CAAA |
|---|---|---|---|---|---|---|---|
| VOC | 25,919 | 24,620 | 17,784 | 26,917 | 14,118 | 31,270 | 13,701 |
| $NO_x$ | 26,261 | 26,848 | 20,817 | 28,692 | 13,639 | 31,714 | 10,077 |
| CO | 155,040 | 127,477 | 107,492 | 134,808 | 86,704 | 155,662 | 84,520 |
| $SO_2$ | 23,818 | 25,406 | 15,320 | 27,086 | 10,348 | 27,914 | 8,306 |
| $PM_{10}$ | 25,469 | 26,422 | 21,145 | 26,411 | 20,441 | 28,279 | 20,599 |
| $PM_{2.5}$ | 7,529 | 8,025 | 5,489 | 8,194 | 5,242 | 8,903 | 5,297 |
| $NH_3$ | 3,659 | 4,137 | 3,982 | 4,407 | 4,224 | 4,786 | 4,585 |

To illustrate and check the reasonableness of the spatial distribution of emissions throughout the modeling domain, daily emission density plots for a selected day were prepared and examined. Figure III-1 presents daily emissions for June 15, 2002 for VOC, NOx, SO2, and $PM_{2.5}$ for the 36-km CONUS grid. As noted above, the meteorological inputs for the modeling exercise are for 2002, while the emissions correspond to the selected study years (1990, 2000, 2010, and 2020). The plots show the spatial distribution of the 2000 emissions, with higher emissions in the more populated areas of the eastern US and California, and lower emissions in the less-populated areas of the interior western US and areas of Canada and Mexico. The VOC emission plots also include biogenic emissions, with higher emissions associated with the more forested regions of the southeast US and Canada. The $PM_{2.5}$ emissions are associated with various anthropogenic mobile and industrial sources, but the high values noted in southwestern Oregon are associated with wildfires.

**Figure III-1a. Daily VOC Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.**

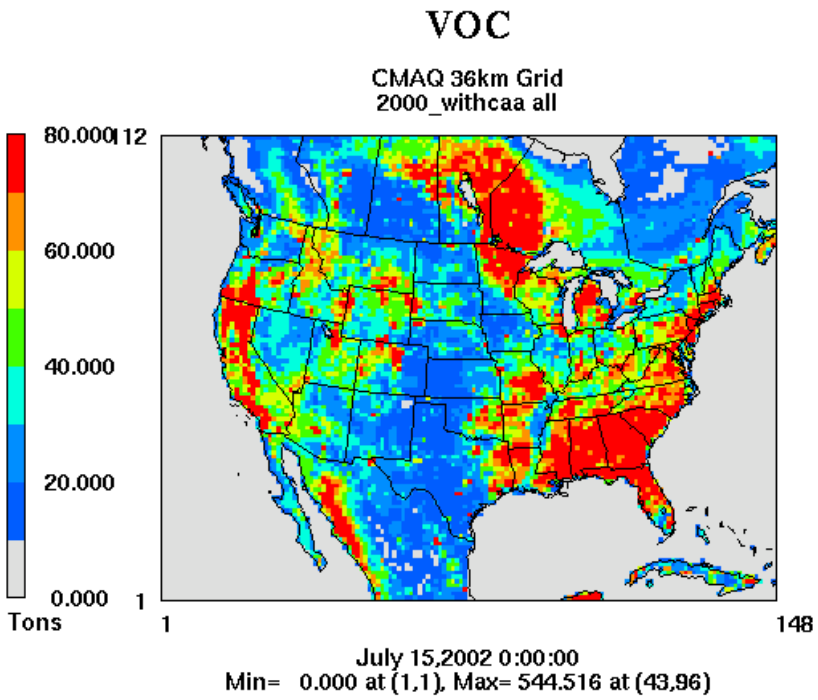



**Figure III-1b. Daily $NO_x$ Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.**

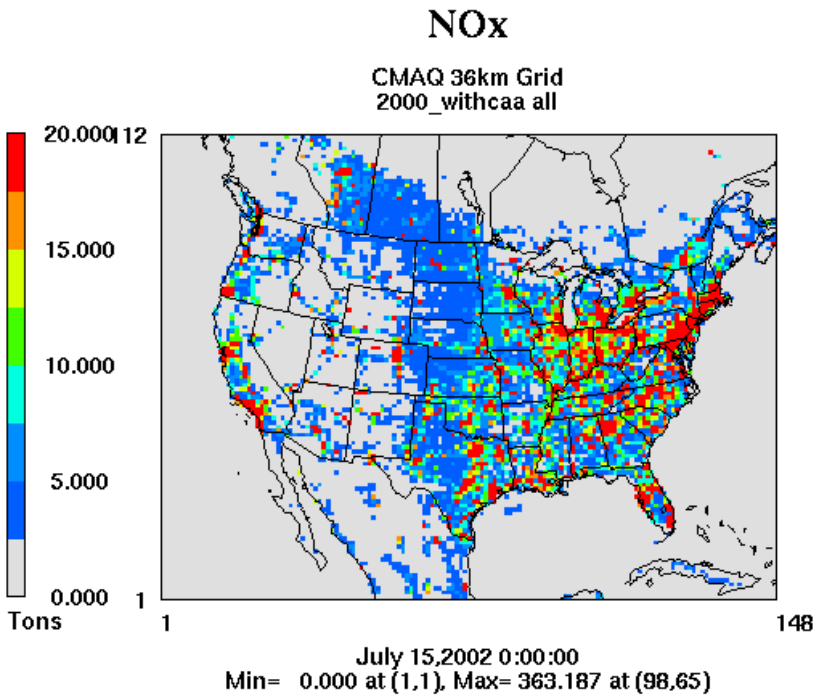


**Figure III-1c. Daily $SO_2$ Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.**

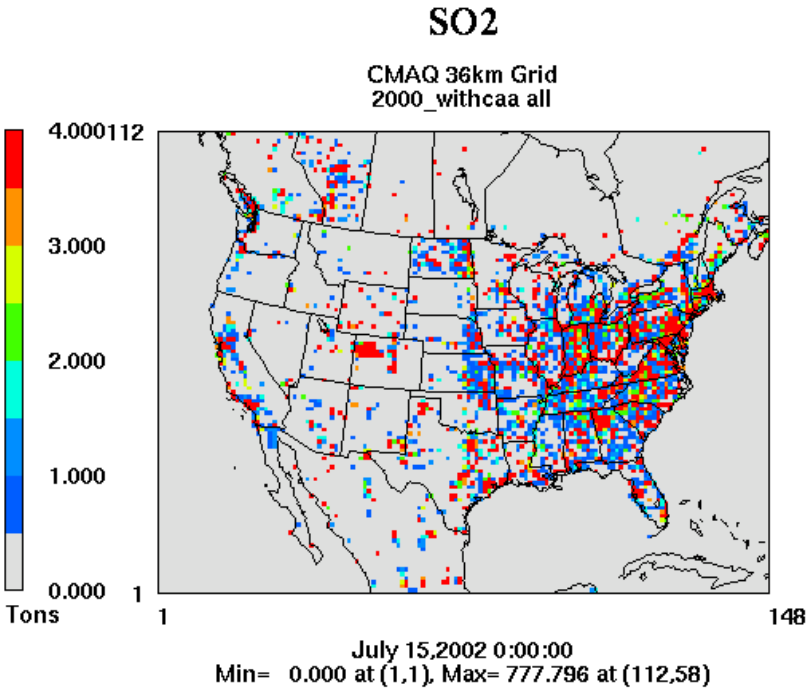
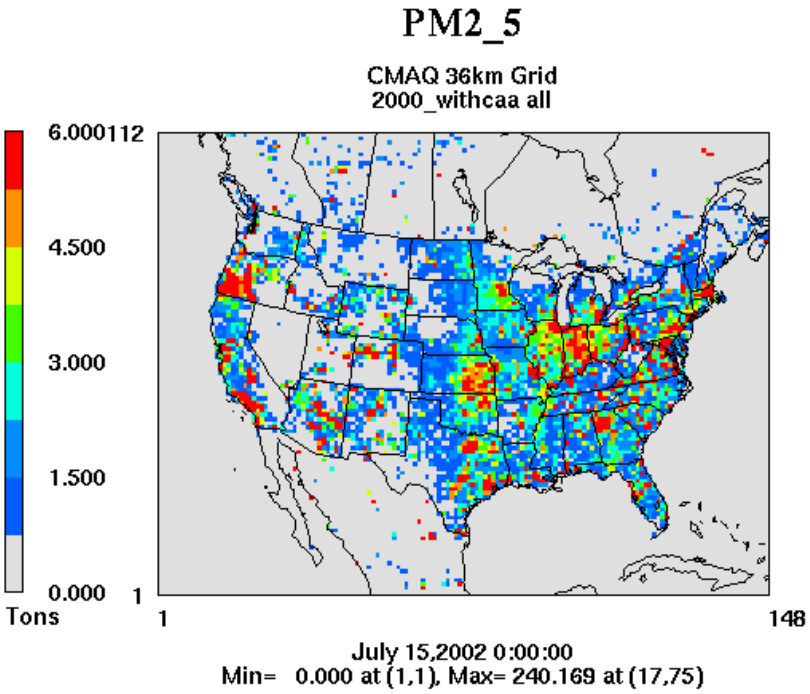



**Figure III-1d. Daily $PM_{2.5}$ Emissions (July 15, 2002) for the 2000 With-CAAA Scenario.**



To illustrate the spatial distribution of expected changes in the emissions for the various modeling scenarios, difference plots comparing the emissions from one scenario with another were prepared and examined. Figure III-2 presents example emissions difference plots for VOC, NOx, $SO_2$, and $PM_{2.5}$, comparing the 2000 with-CAAA scenario with the 2020 with-CAAA scenario. The figures illustrate where the reductions in emissions are expected to occur throughout the 36-km resolution CONUS modeling domain. For VOC emissions, there are expected decreases in 2020 throughout the eastern US, especially in the northeast urban corridor. Additional large reductions are found in Chicago, Houston, Dallas, and the Greater Las Angeles area. Emissions of NOx are expected to decrease substantially throughout the eastern US, Canada, and California. The decreases are more widespread than those for SO2, which are primarily associated with industrial point sources, such as EGUs. Some slight areas of increases in VOC, NOx, and $SO_2$ emissions are the result of new sources or inconsistencies in the origin of the datasets used to prepare the base and future year estimates. The majority of the emissions reductions for $PM_{2.5}$ are from area sources in population centers and from non-EGU industrial sources located throughout the US.

**Figure III-2a. Differences in Daily VOC Emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).**

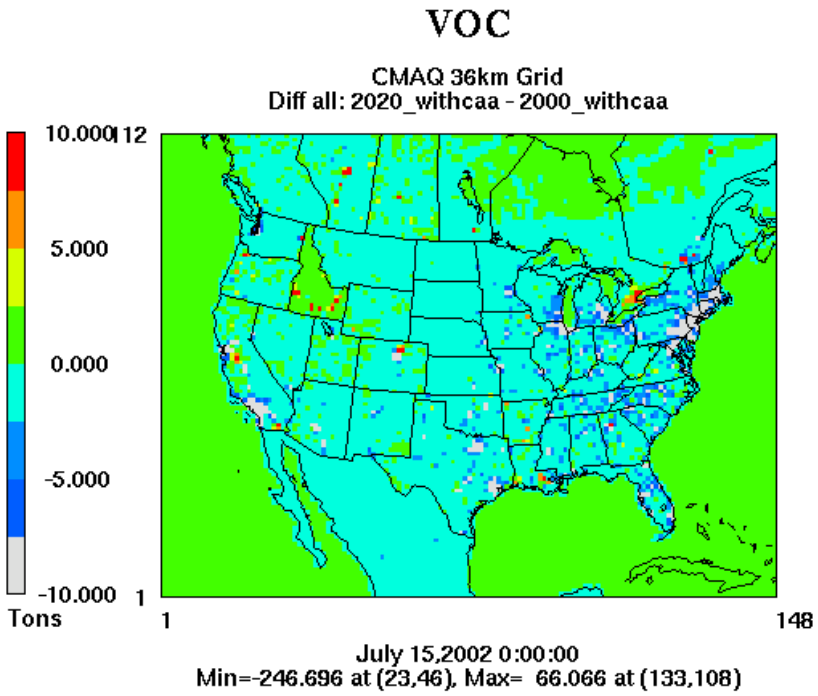


**Figure III-2b. Differences in Daily $NO_x$ Emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).**

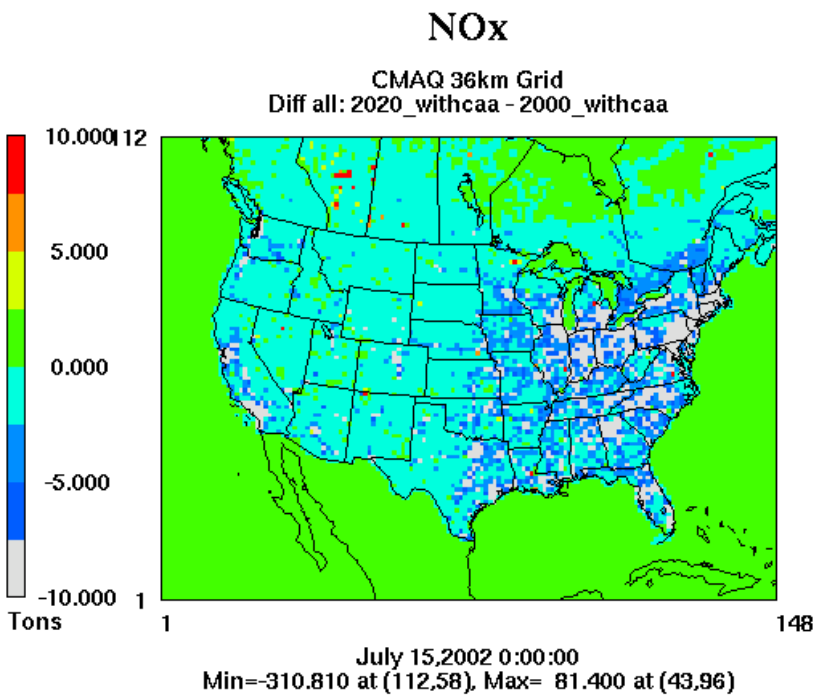



**Figure III-2c. Differences in Daily $SO_2$ Emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).**

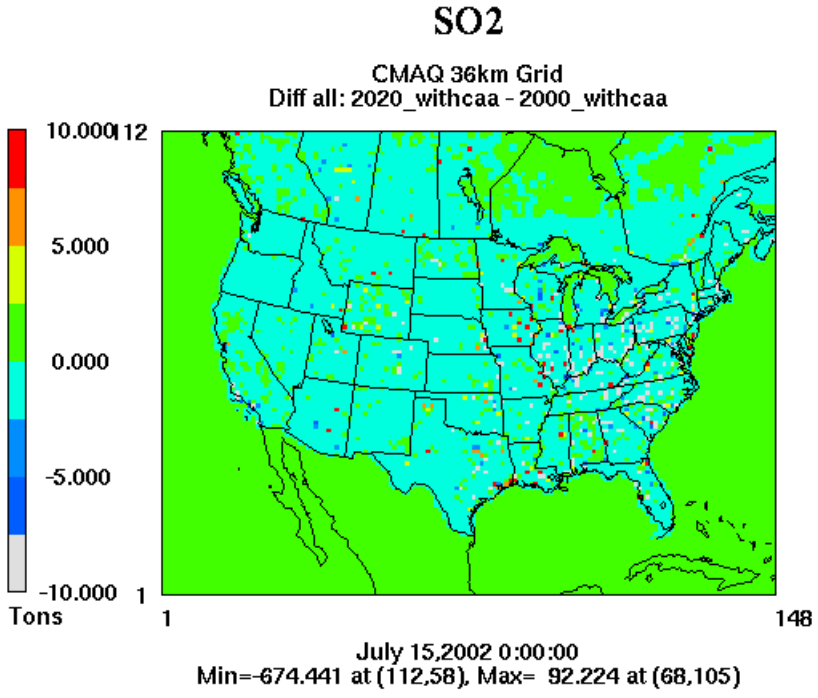
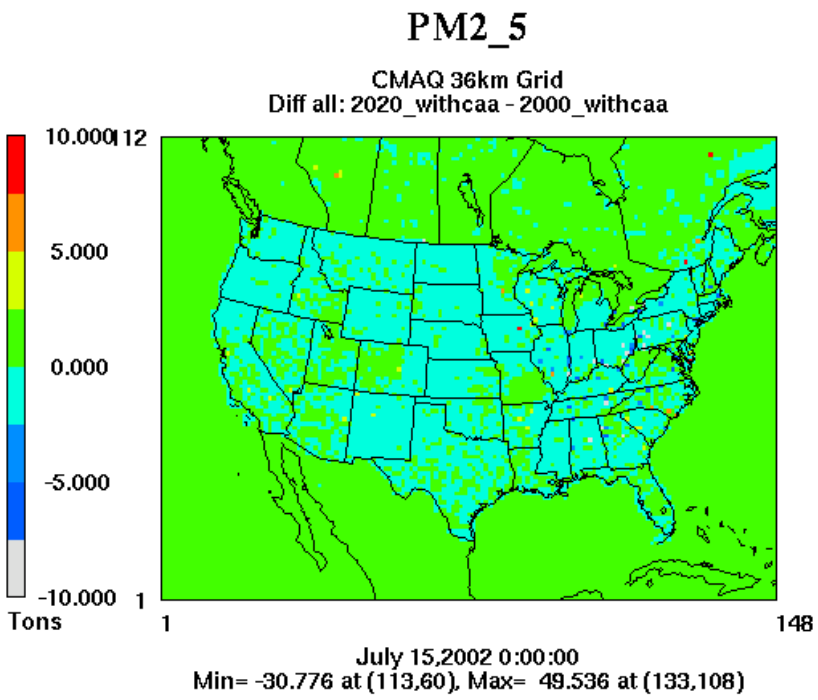


**Figure III-2d. Differences in Daily $PM_{2.5}$ emissions (July 15) (2020 With-CAAA Minus 2000 With-CAAA).**




In addition to spatial emission density figures, tabular summaries were also prepared for each of the scenario inventories. Figure III-3 presents national emissions estimates by source sector for all of the scenarios for VOC, NOx, $SO_2$, and $PM_{2.5}$.

**Figure III-3a. National Emission Totals for VOC for the 812 Modeling Analysis Scenarios.**

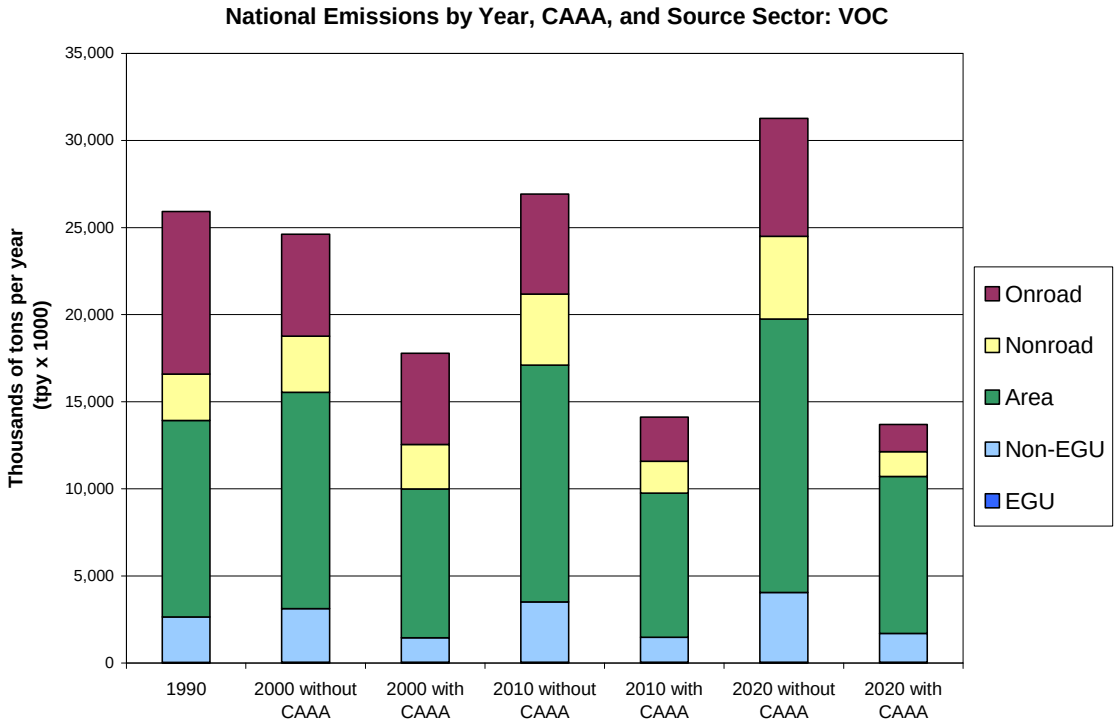



**Figure III-3b. National Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios.**

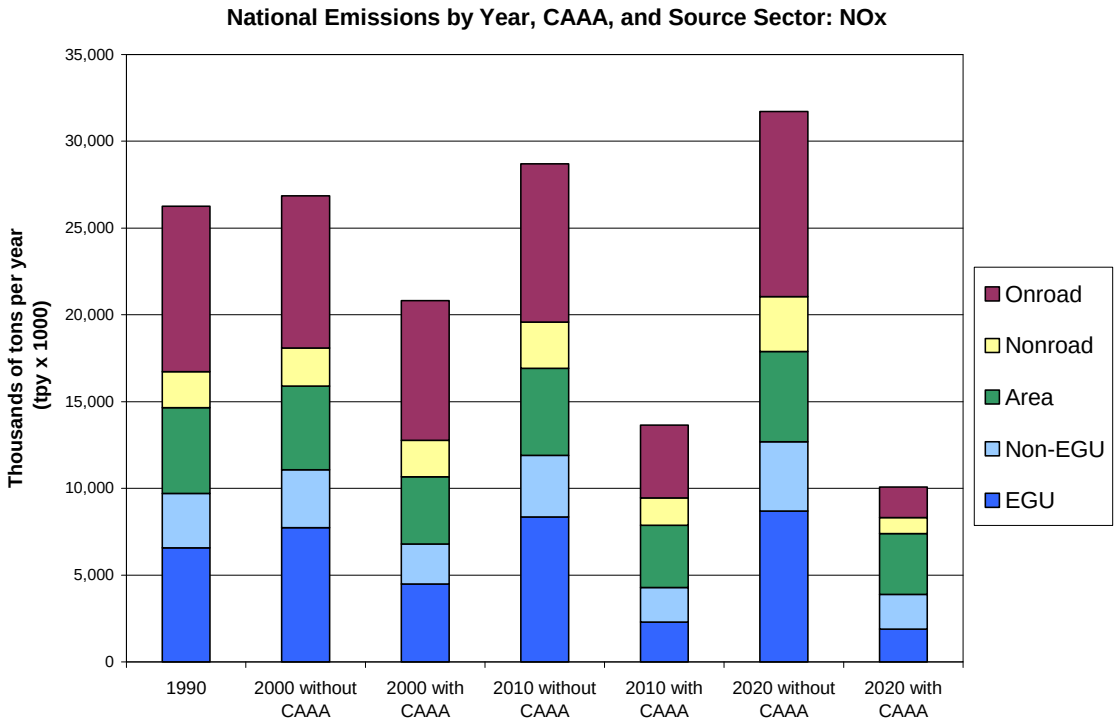


**Figure III-3c. National Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios.**

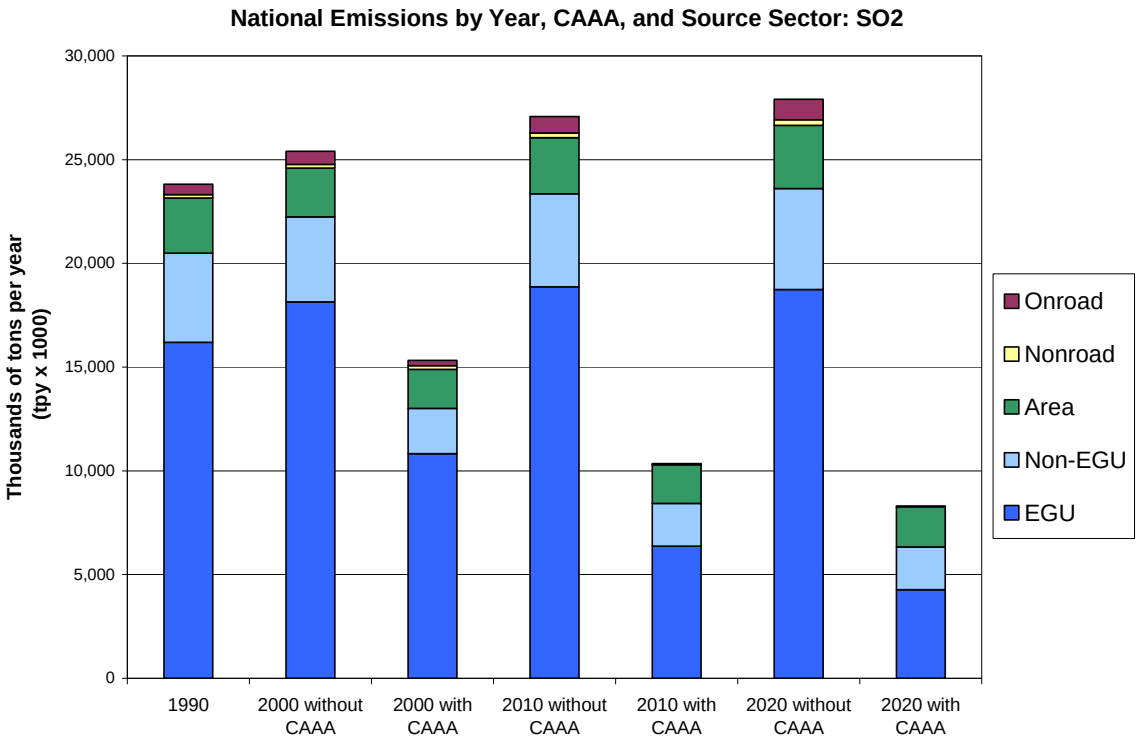
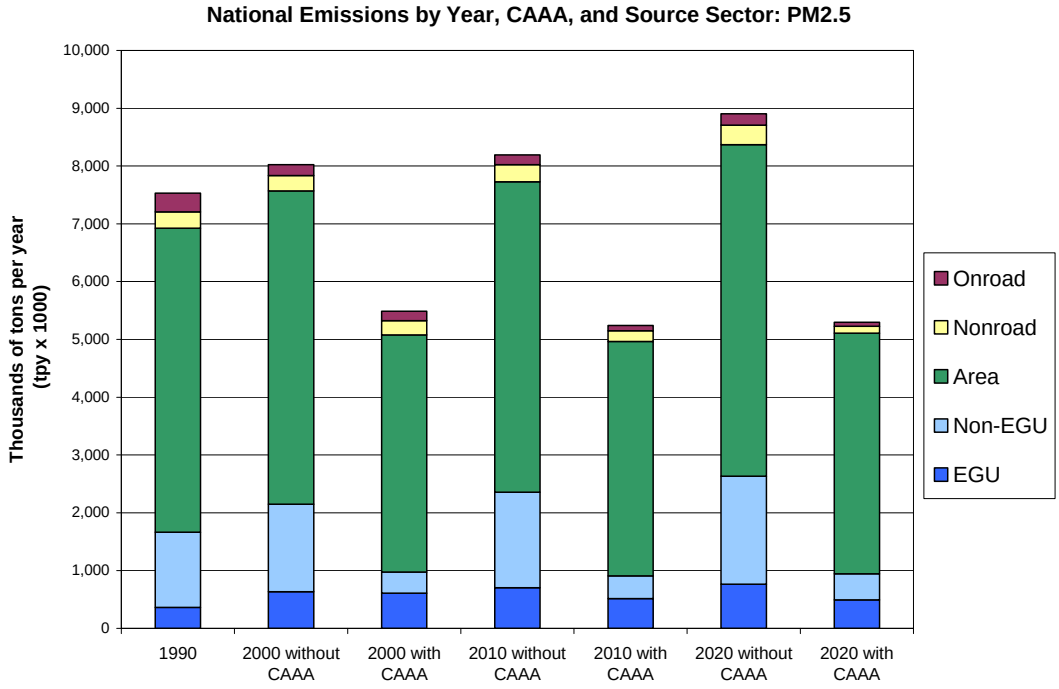



**Figure III-3d. National Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios.**



As depicted in the figures, anthropogenic VOC emissions are primarily from on-road and area sources, NOx emissions are primarily from on-road and EGU sources, $SO_2$ emissions are primarily from EGU sources, and $PM_{2.5}$ emissions are primarily from area sources. Although the magnitude of emissions varies from region to region across the nation, the dominant source categories for each species are very consistent. An examination of the 48-state emission totals for the various emission scenarios that do not include CAAA controls shows an estimated increase in emissions in the future years (2010 & 2020) compared to the 2000 base year. This reflects the expected growth in population and the resulting increase in industrial, transportation, and energy-related activities/sources. Without CAAA controls, emissions for VOC, NOx, $SO_2$, and $PM_{2.5}$ are estimated to increase approximately 28, 18, 9, and 6 percent, respectively, by 2020, from the 2000 base year estimates that also do not include CAAA controls.

The future-year inventories that include CAAA controls show an estimated decrease in VOC, NOx, $SO_2$, and $PM_{2.5}$ emissions by 2020 of 22, 51, 47, and 4 percent, compared to the 2000 inventory with CAAA controls. Between 2000 and 2020, the largest percentage emission reductions are expected for VOC in the on-road mobile sector (from I/M programs, reformulated gasoline, RVP controls, oxygenated fuel, etc.), for NOx in the on-road mobile (same control programs as for VOC) and EGU sectors (from CAIR, CAMR, NOx SIP Call, RACT, etc.), for $SO_2$ in the EGU sector (from CAIR, RACT, etc.), and for $PM_{2.5}$ from all sectors (comparable small reductions due to various controls). On a percentage basis, $PM_{2.5}$ emissions are reduced by the largest amount for the non-EGU sources.

The overall magnitude and spatial differences within the 48 states in expected future increases/decreases in emissions depends on the specific source make-up of the geographic region. The more populated regions are dominated by mobile and area sources. To provide a comparison of the regional differences in the source characteristics and the magnitude of emissions, emissions totals are presented for six selected states, including Massachusetts, Pennsylvania, Georgia, Illinois, Colorado, and Washington. Figures III-4, III-5, III-6, and III-7 present emissions for each of the scenarios, respectively for VOC, NOx, $SO_2$, and $PM_{2.5}$, comparing component totals for each of these states for each of the 812 modeling scenarios. To facilitate the state-by-state comparisons, the species-specific scales of the plots are the same for each state.

**Figure III-4a. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Massachusetts.**

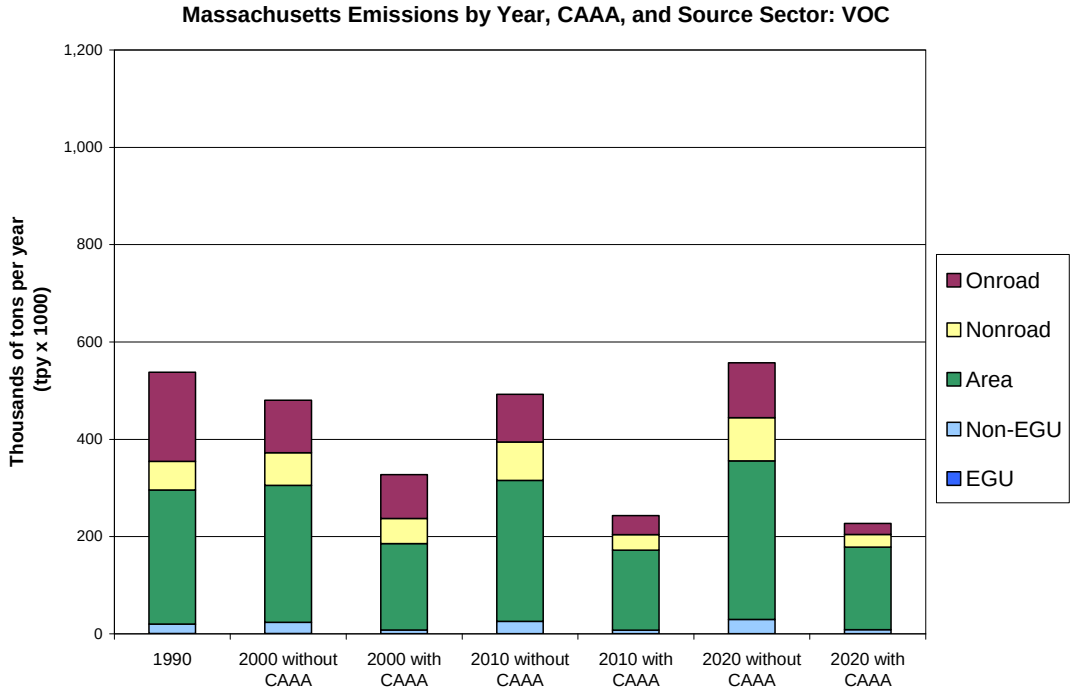



**Figure III-4b. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Pennsylvania.**

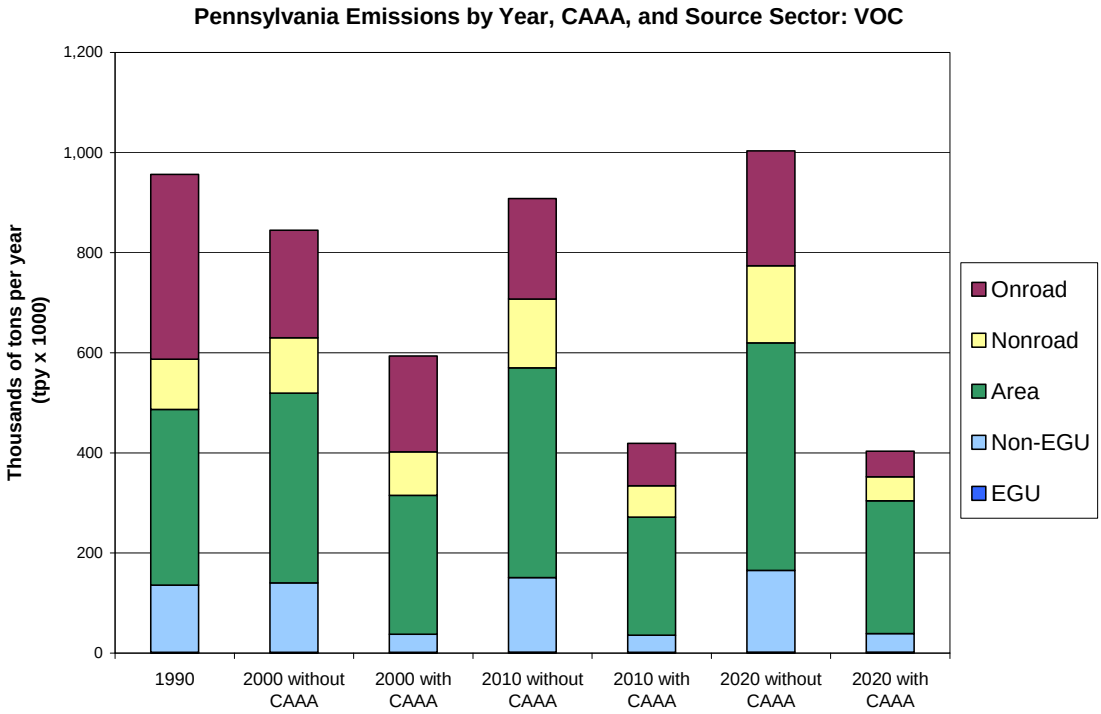


**Figure III-4c. Emission totals for VOC for the 812 Modeling Analysis Scenarios for Georgia.**

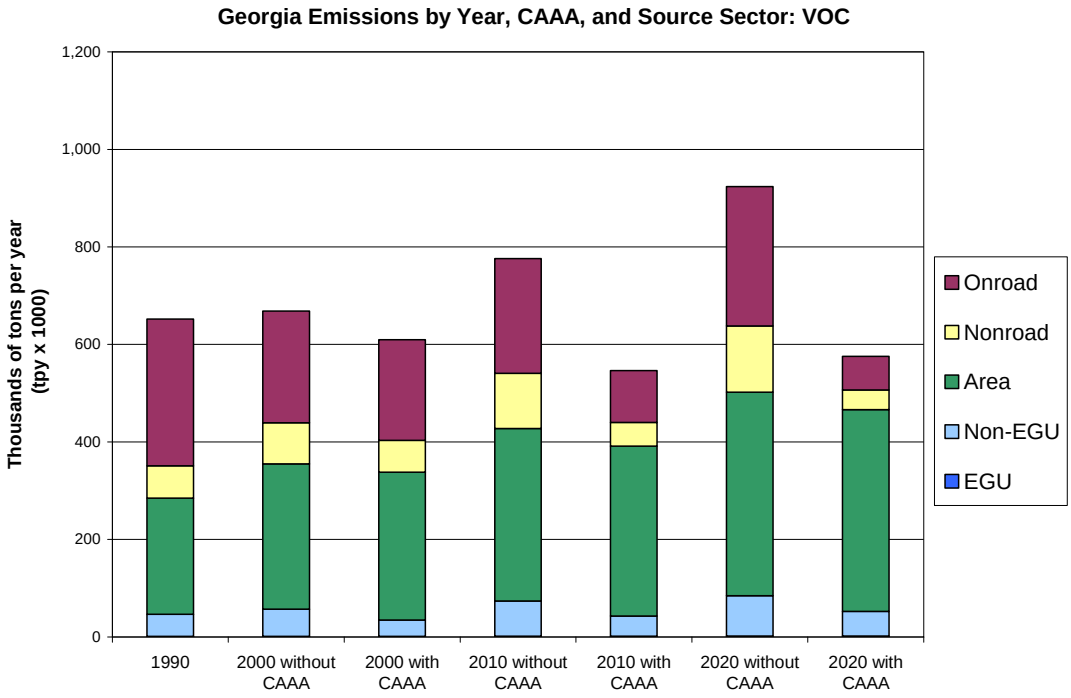



**Figure III-4d. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Illinois.**

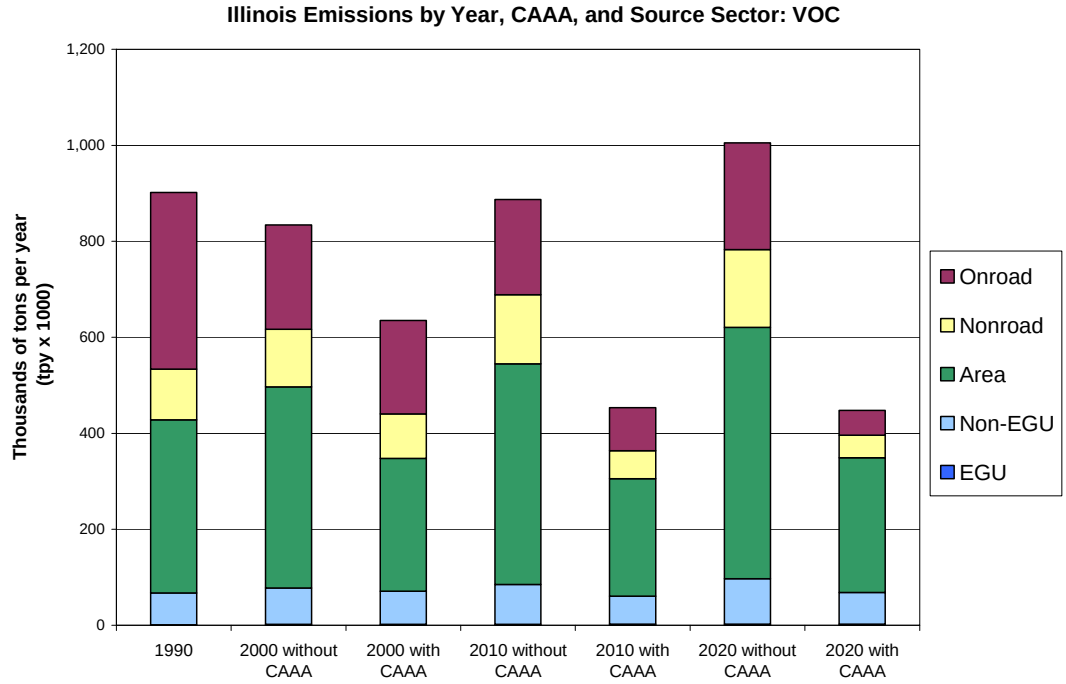


**Figure III-4e. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Colorado.**

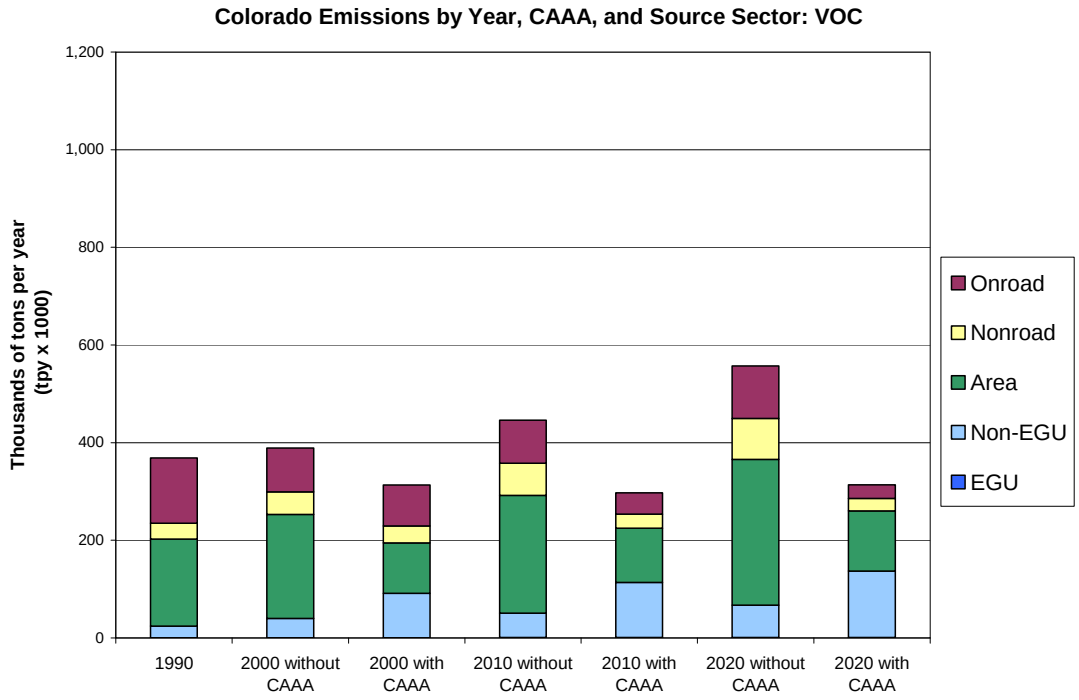



**Figure III-4f. Emission Totals for VOC for the 812 Modeling Analysis Scenarios for Washington.**

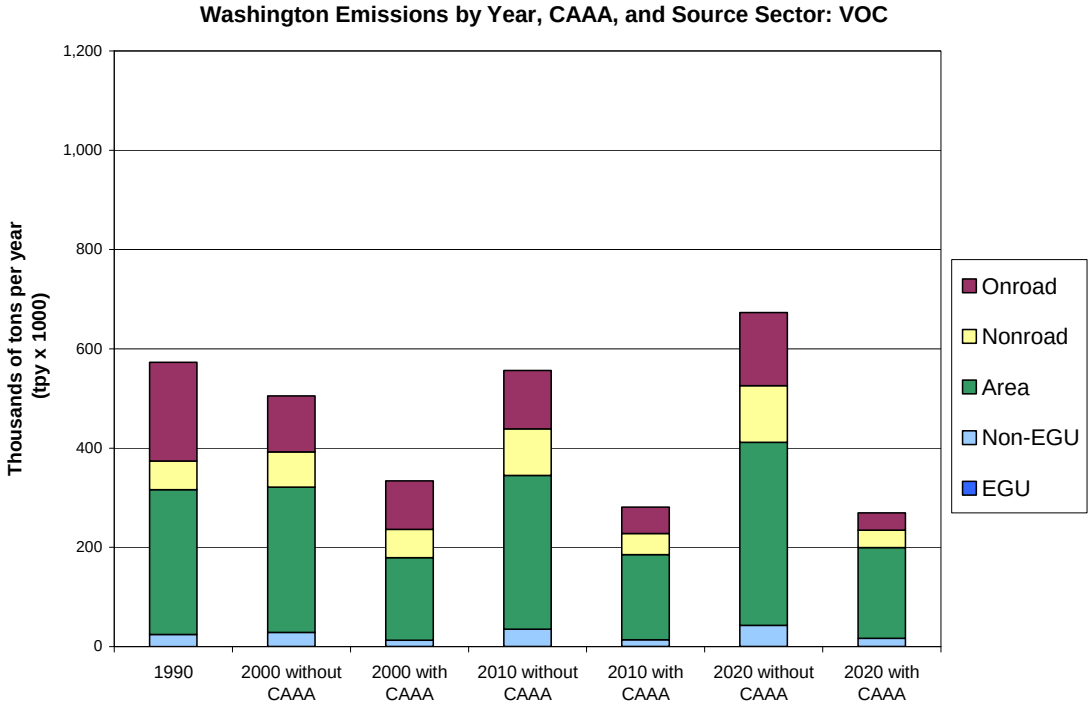


**Figure III-5a. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Massachusetts.**

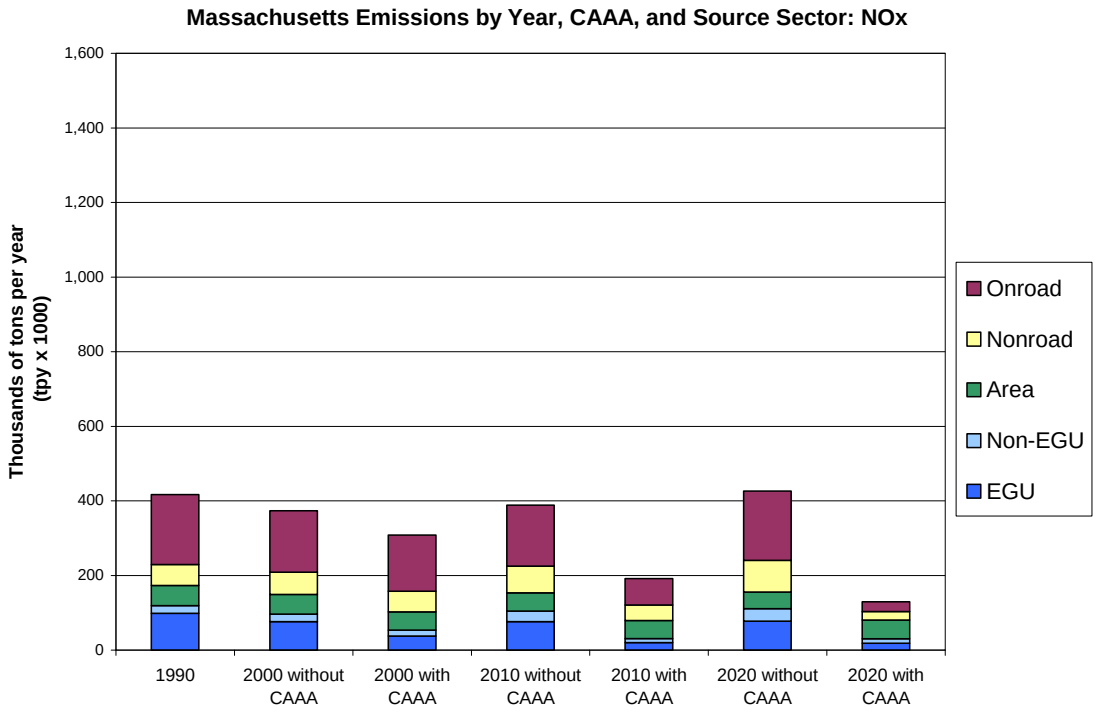



**Figure III-5b. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Pennsylvania.**

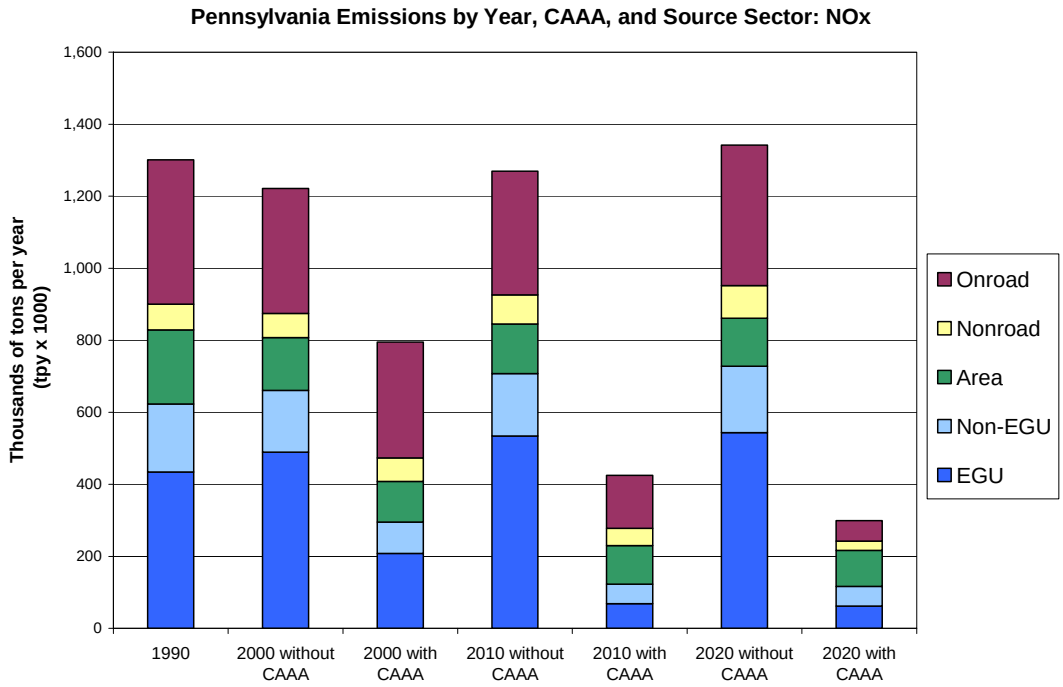


**Figure III-5c. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Georgia.**

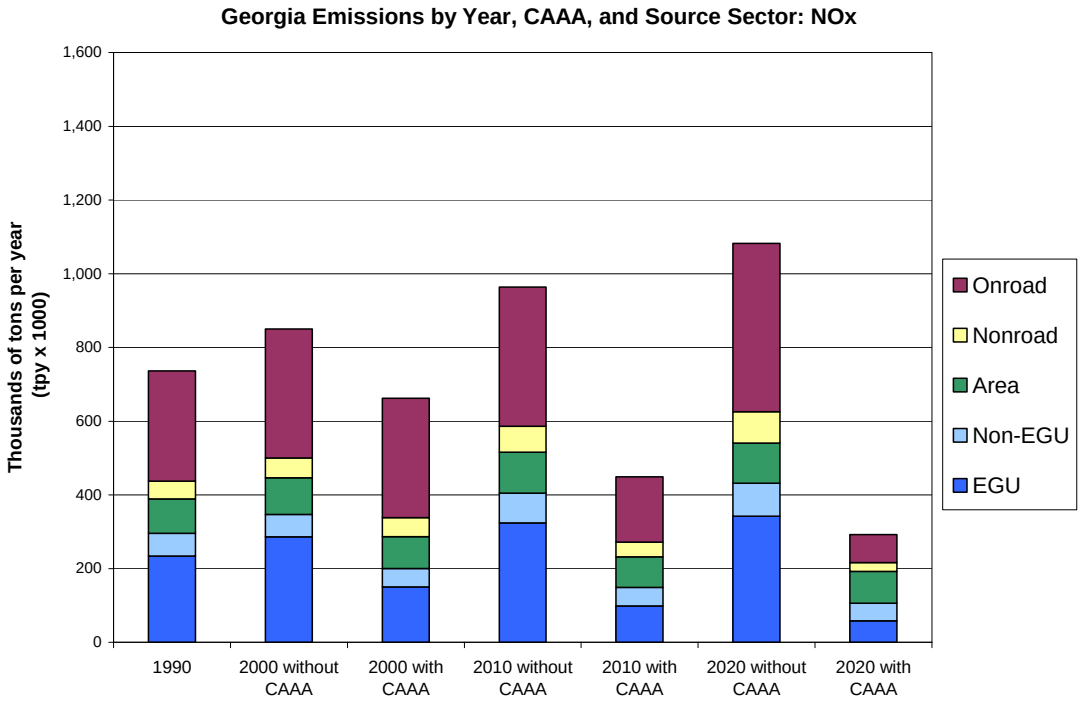



**Figure III-5d. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Illinois.**

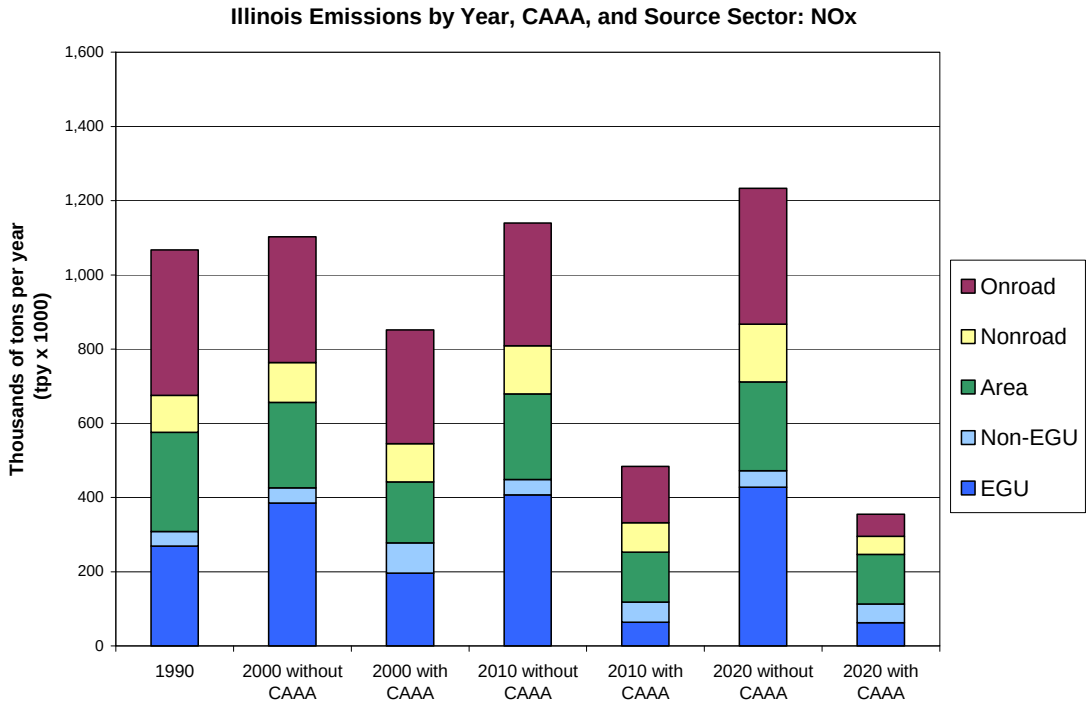


**Figure III-5e. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Colorado.**

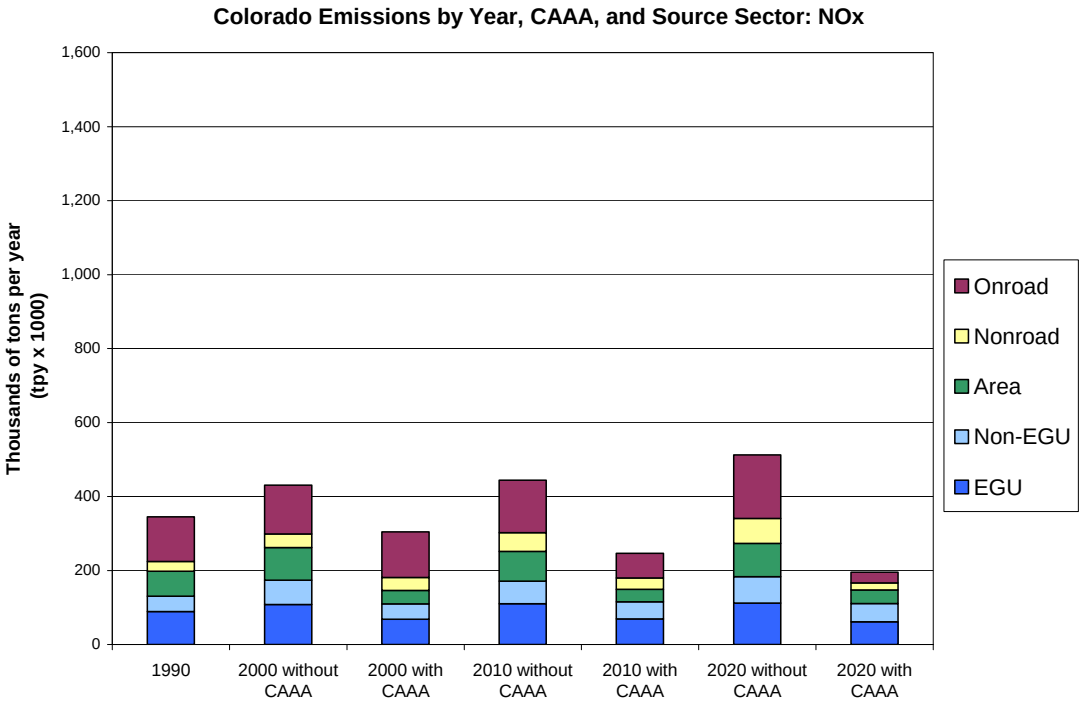



**Figure III-5f. Emission Totals for $NO_x$ for the 812 Modeling Analysis Scenarios for Washington.**

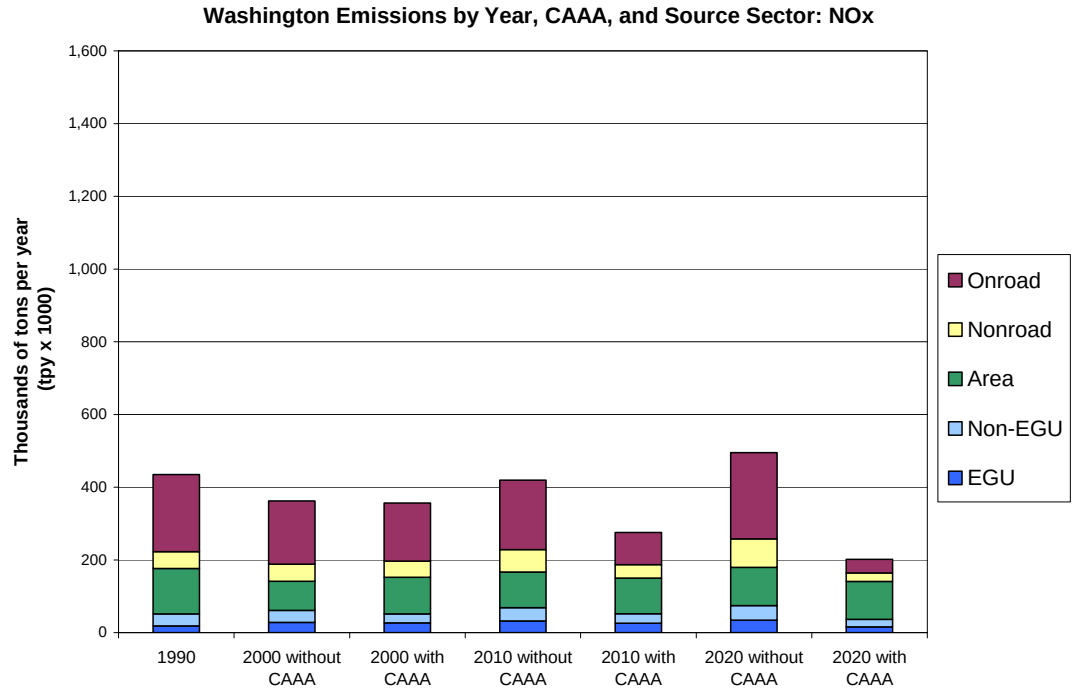


**Figure III-6a. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Massachusetts.**

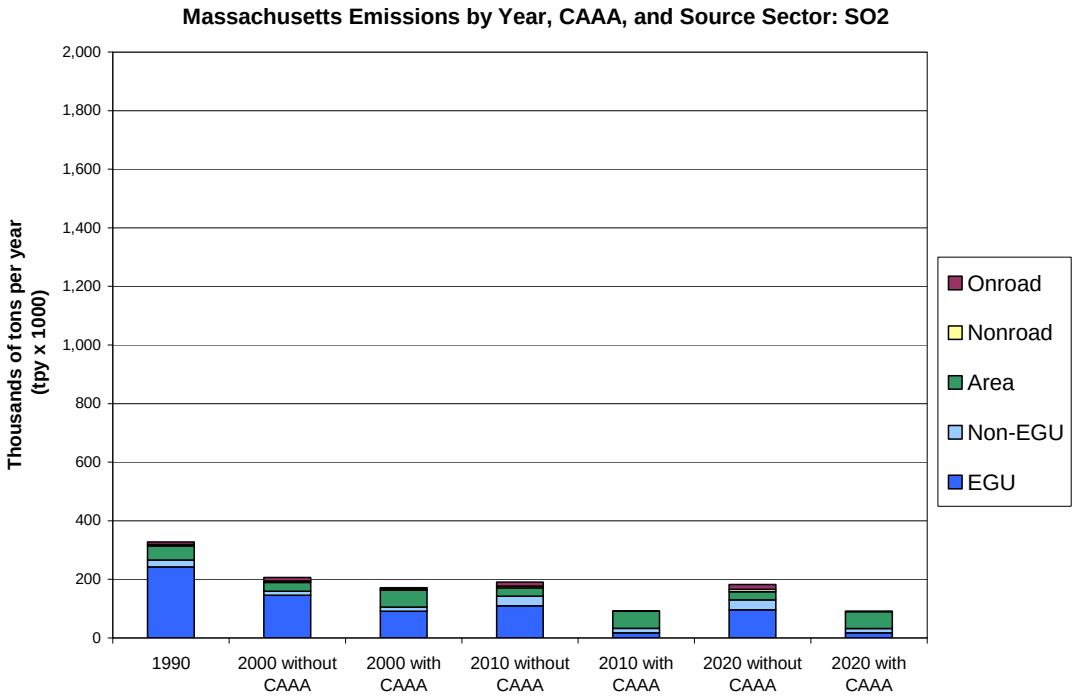



**Figure III-6b. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Pennsylvania.**

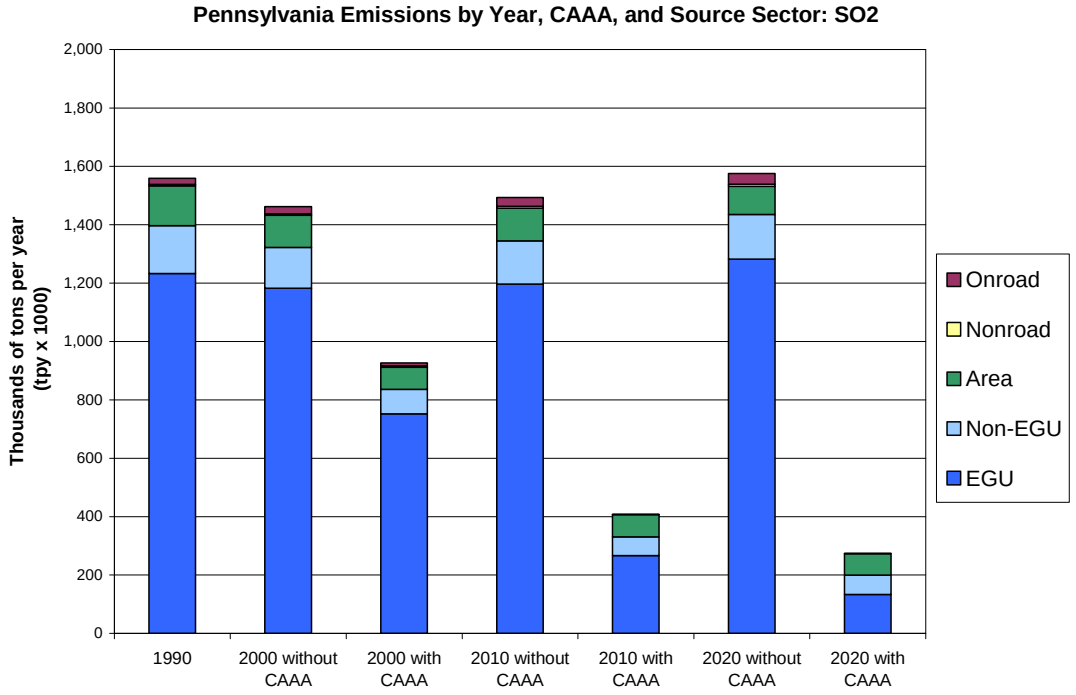


**Figure III-6c. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Georgia.**

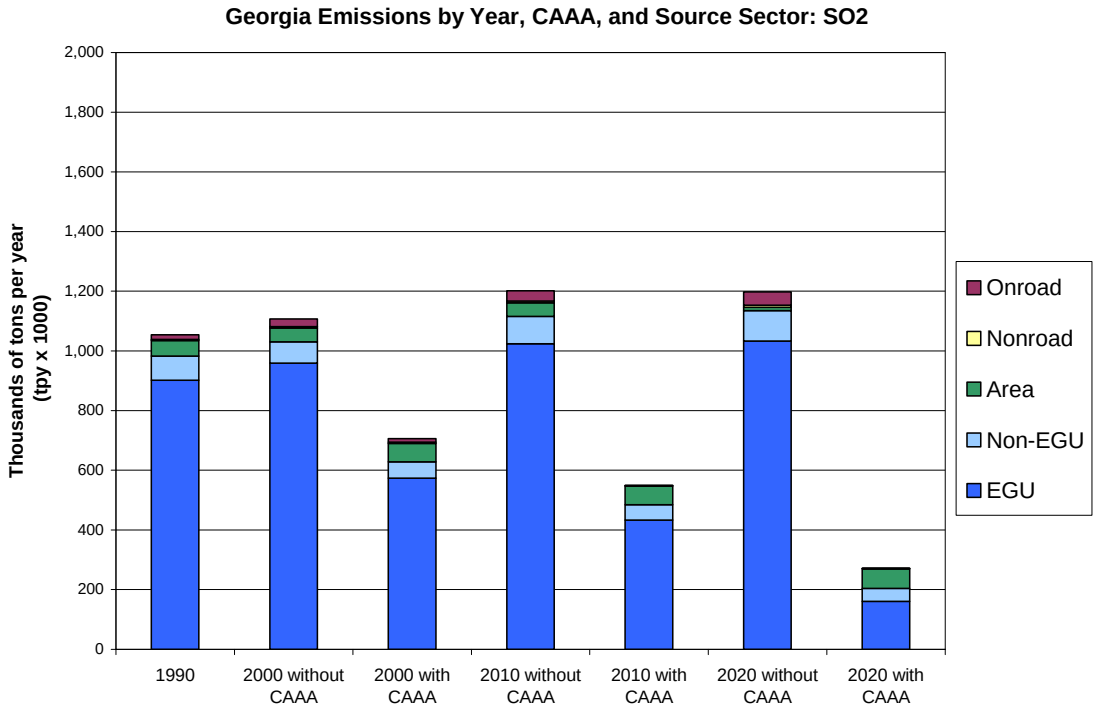



**Figure III-6d. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Illinois.**

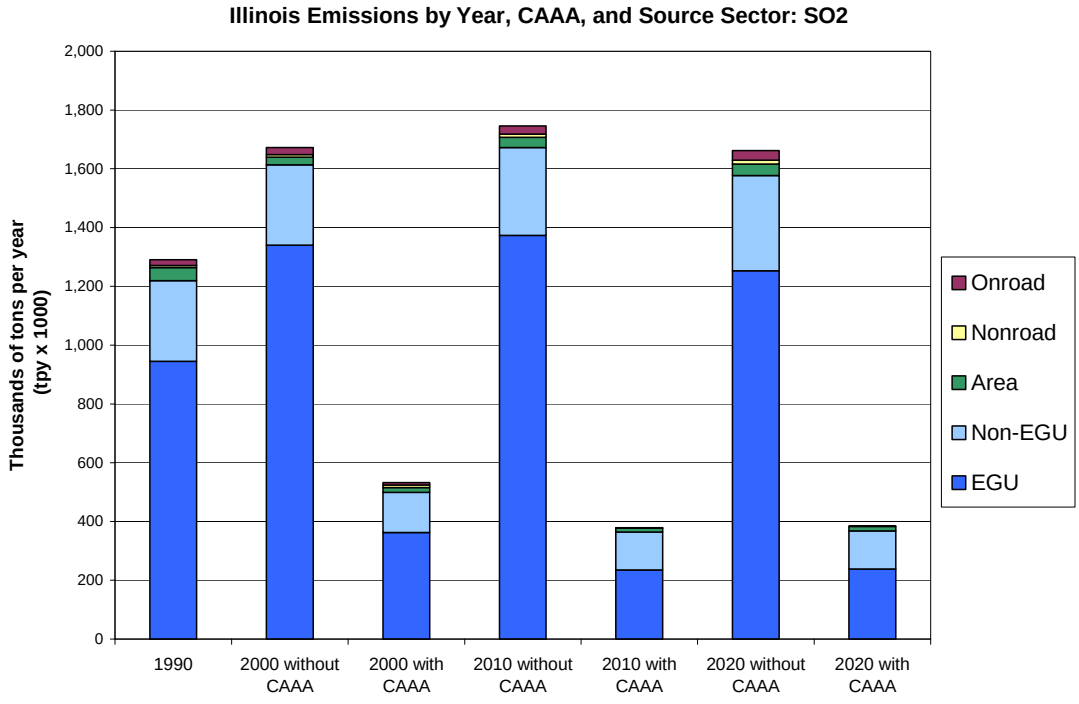


**Figure III-6e. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Colorado.**

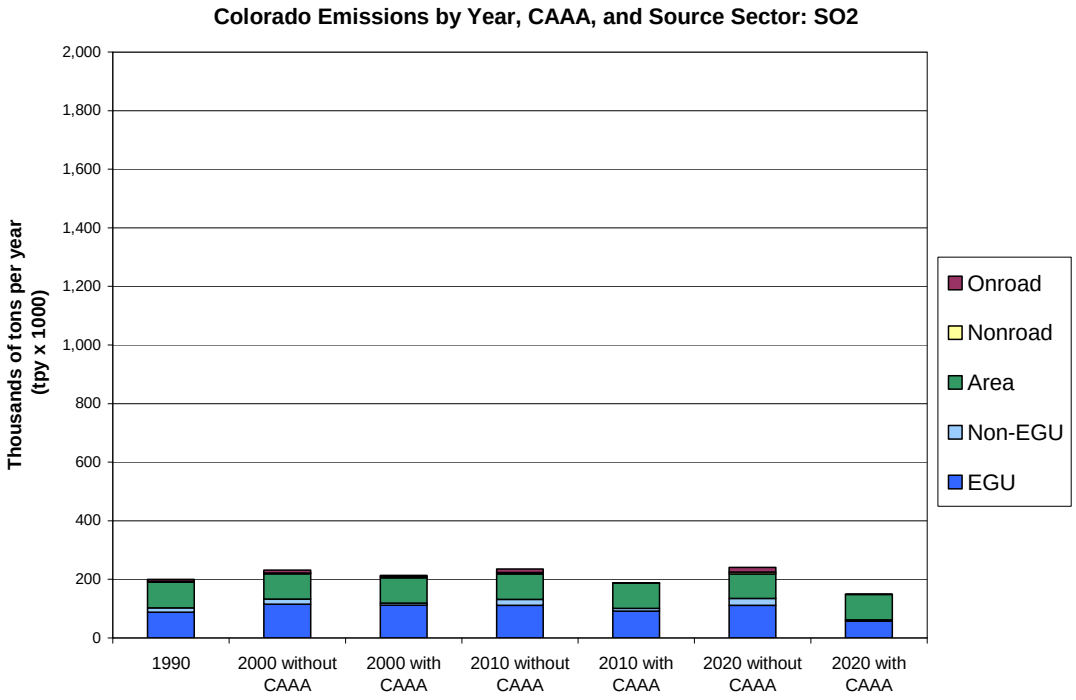



**Figure III-6f. Emission Totals for $SO_2$ for the 812 Modeling Analysis Scenarios for Washington.**

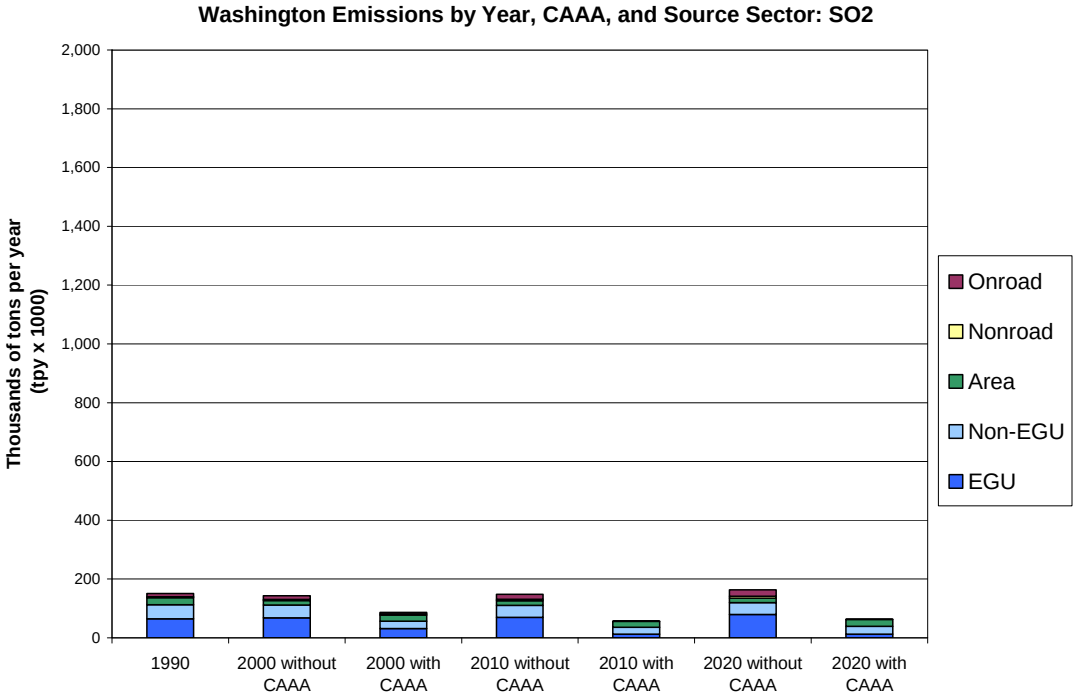


**Figure III-7a. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Massachusetts.**

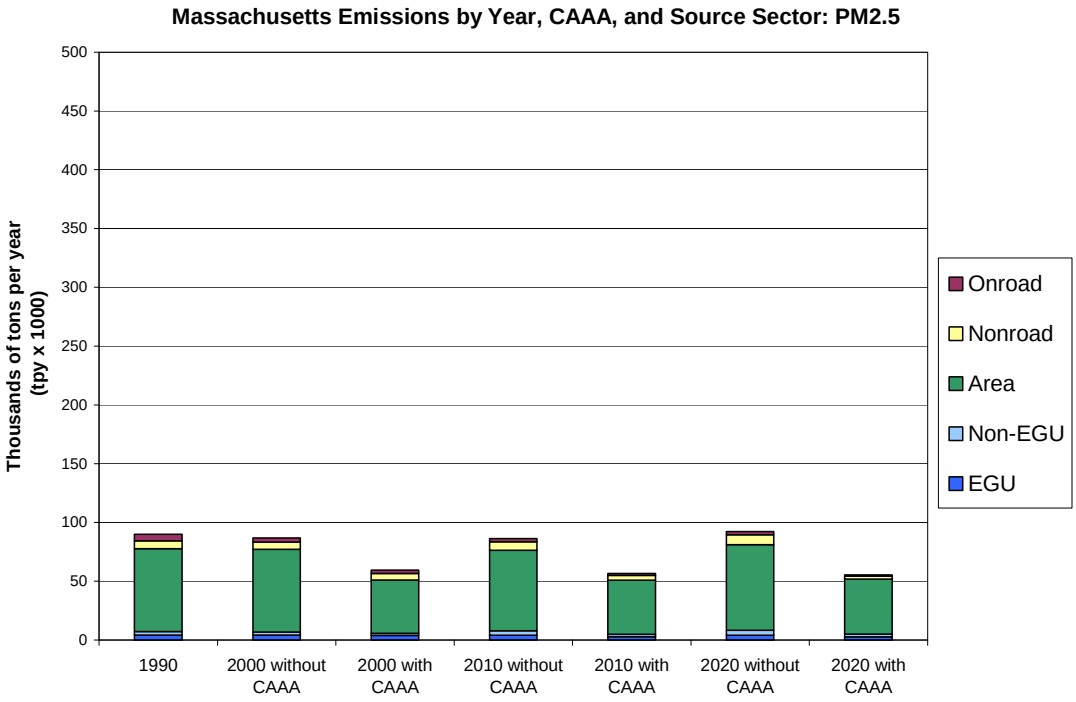



**Figure III-7b. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Pennsylvania.**

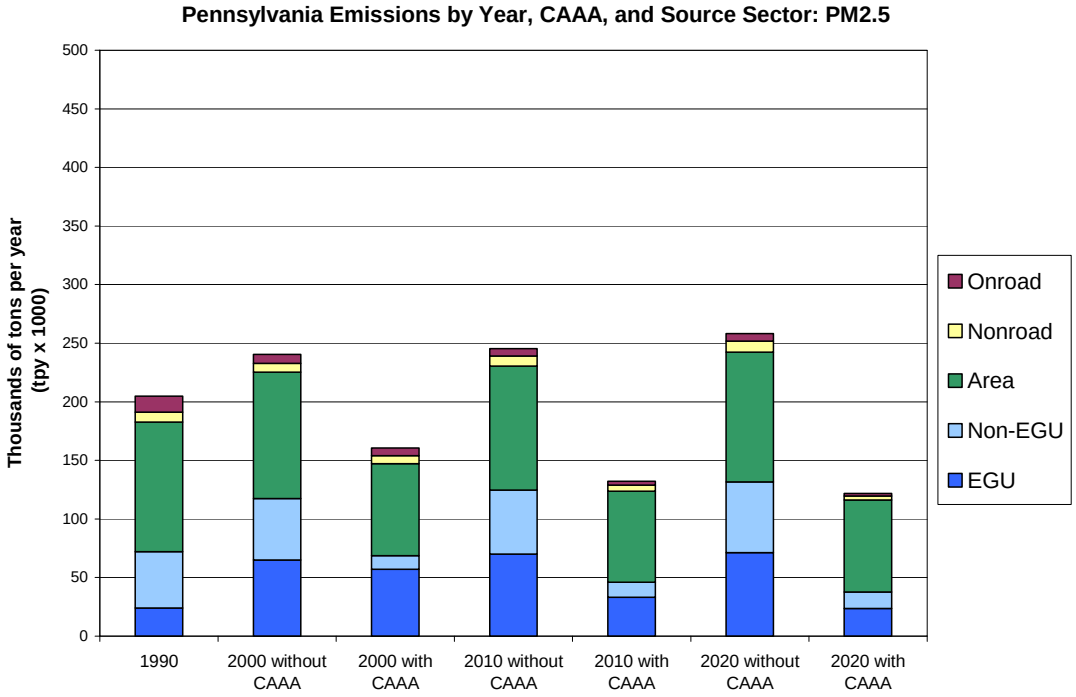


**Figure III-7c. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Georgia.**

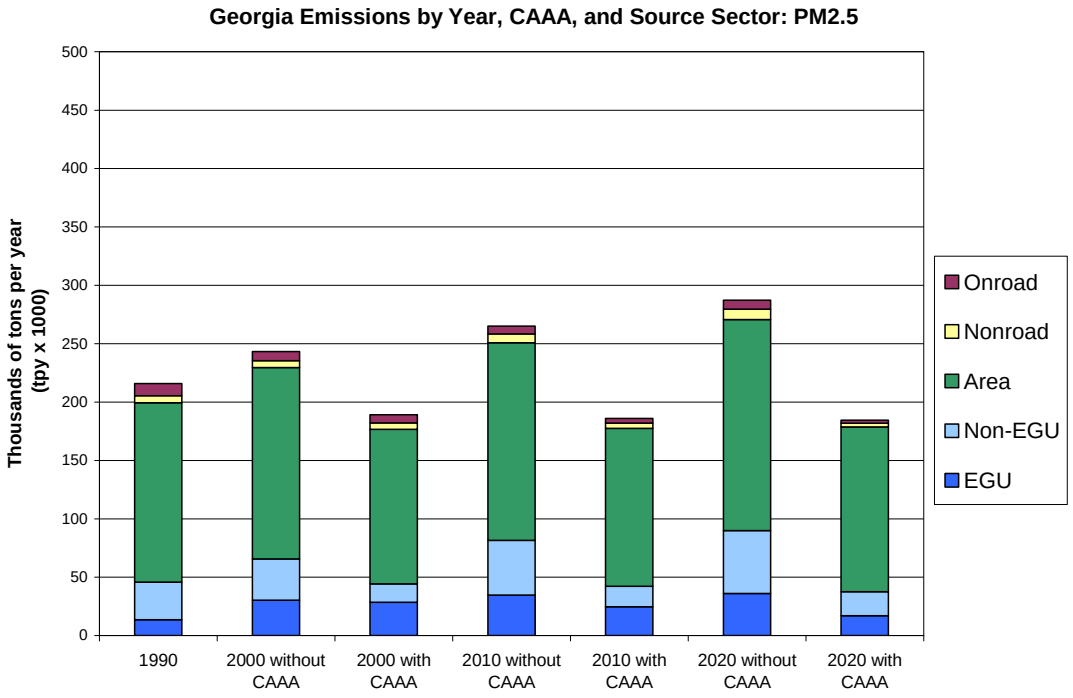



**Figure III-7d. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Illinois.**

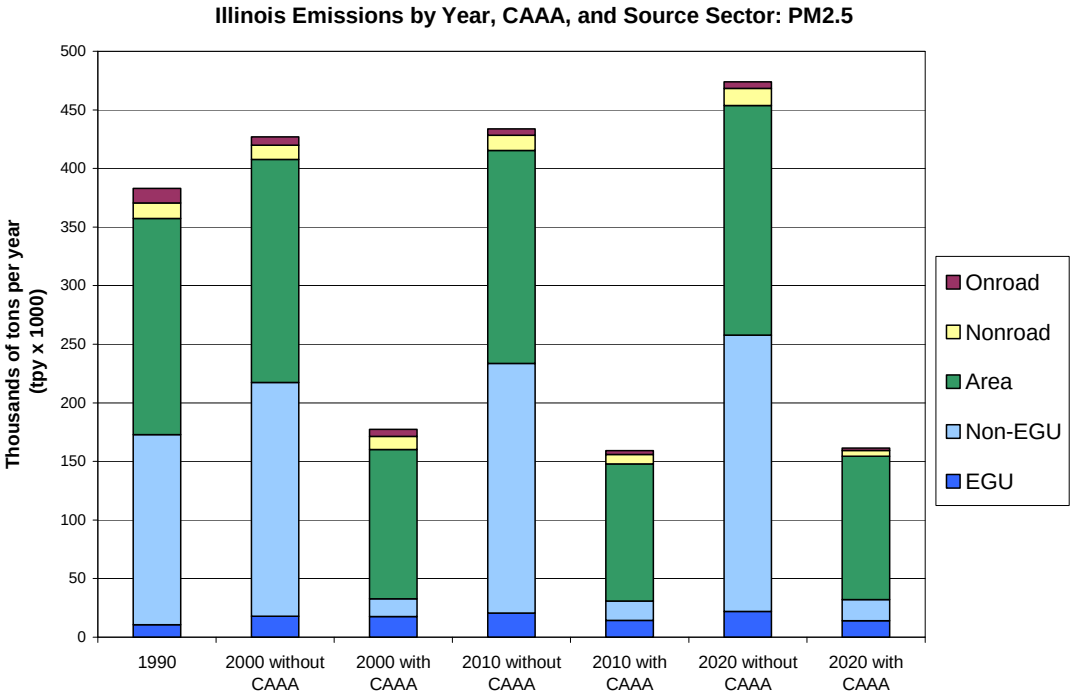


**Figure III-7e. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Colorado.**

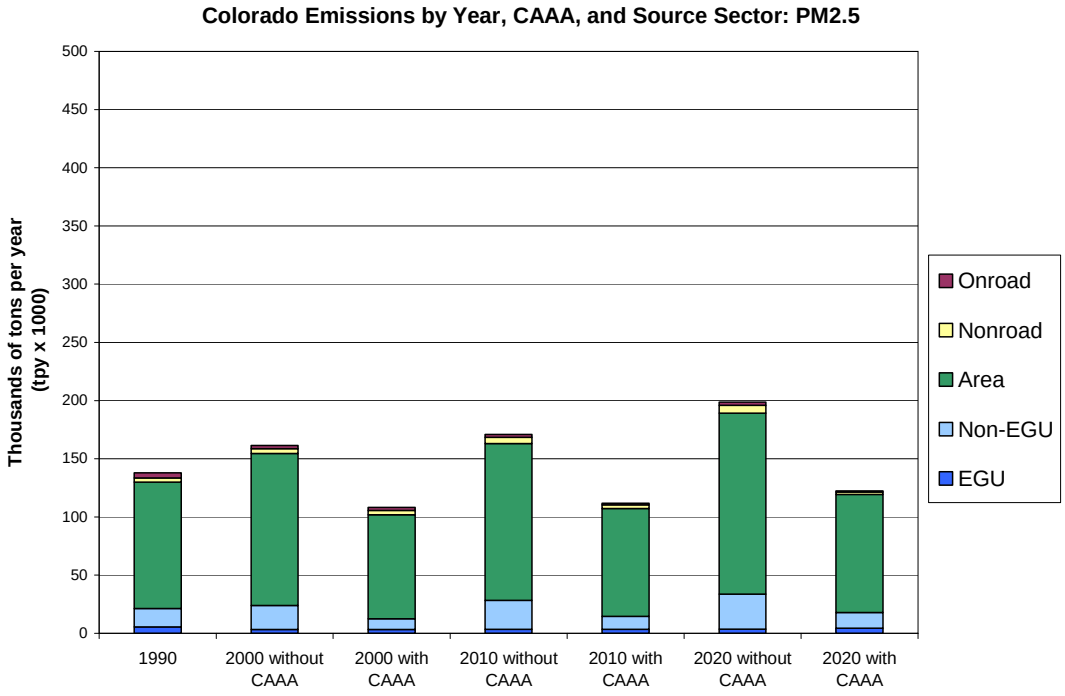
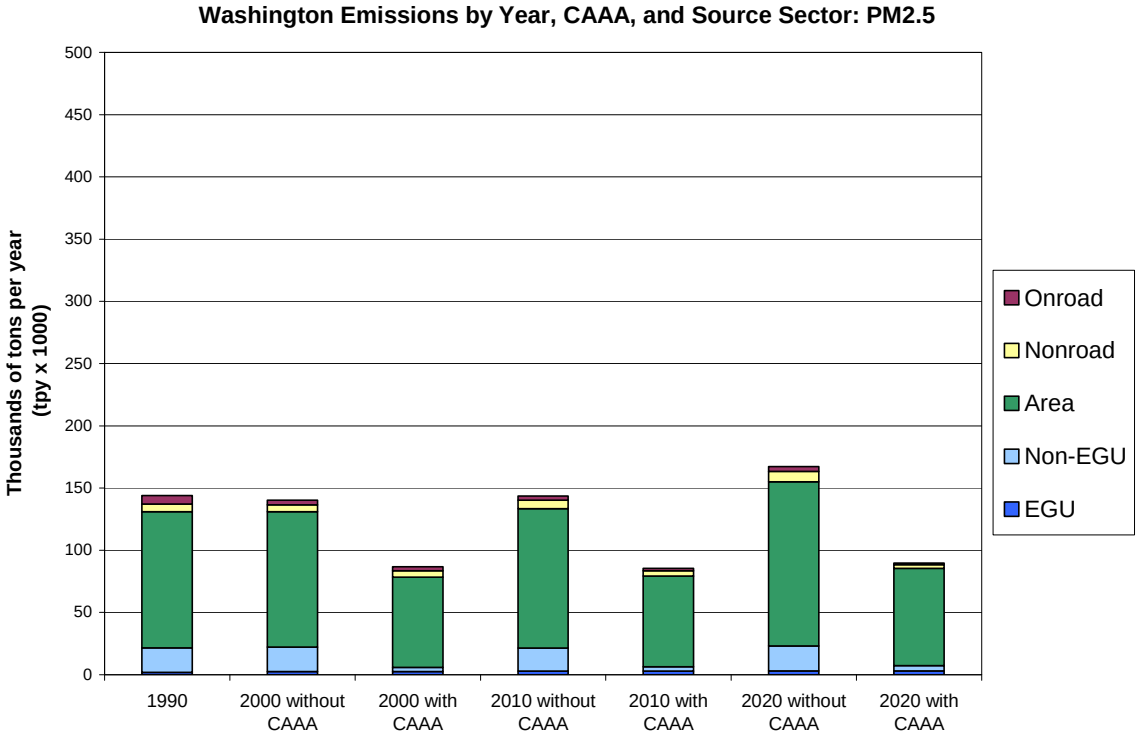



**Figure III-7f. Emission Totals for $PM_{2.5}$ for the 812 Modeling Analysis Scenarios for Washington.**



The state anthropogenic VOC emission totals presented in Figure III-4 are consistent with the national estimates and are dominated by on-road mobile and area sources. They reflect similar expected increases in emissions for the without-CAAA inventories (due to growth in population and activity) and similar decreases in emissions for the with-CAAA inventories, reflecting both growth and applicable control programs. The expected reductions in VOC emissions are derived from controls primarily from the on-road mobile sector, with additional reductions derived from all other sectors, with the exception of EGUs. The differences in magnitude of the VOC emissions reflect mainly state-by-state differences in population and accompanying motor vehicle activity, with Pennsylvania having the highest anthropogenic VOC emissions and Colorado having the lowest, of these states.

The state-specific NOx and $SO_2$ emissions totals presented in Figures III-5 and III-6, respectively, reflect differences in both population and the location of major EGU sources. Of the states presented, Pennsylvania and Illinois have the highest emissions and contribution of EGU sources while the states of Colorado and Washington have the lowest. The expected future-year reductions in NOx emissions are derived from both the on-road mobile and EGU sectors, while the expected future-year reductions in $SO_2$ are from the EGU sector.

For the state-specific $PM_{2.5}$ emissions, the source sector totals also reflect the types of sources operating in each of the states, with some states (e.g., Pennsylvania and Illinois) showing higher percentage contributions from non-EGU sources, reflecting industrial activity, compared to the State of Massachusetts, with a small number of non-EGU point sources. The expected future-year $PM_{2.5}$ emission reductions resulting from the CAAA are quite large for non-EGU sources (greater than 50 percent reduction) in Pennsylvania, Georgia, Colorado, and Washington, with an expected reduction of over 90 percent for the State of Illinois, likely the result of controls on metal processing and other industrial activity in the Greater Chicago area. This results in expected reductions in primary $PM_{2.5}$ emissions in these areas of 40-60 percent, which could greatly affect the locally simulated $PM_{2.5}$ concentrations for these areas. This will also depend on the local chemistry and resulting composition of total PM.

# Section IV
# Air Quality Modeling

## Overview of the CMAQ Modeling System

The Community Multiscale Air Quality (CMAQ) model is a state-of-the-science, regional air quality modeling system that can be used to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere (Byun and Ching, 1999). The CMAQ tool was designed to improve the understanding of air quality issues (including the physical and chemical processes that influence air quality) and to support the development of effective emissions control strategies on both the regional and local scale. The CMAQ model was designed as a "one-atmosphere" model and this concept refers to the ability of the model to dynamically simulate ozone, particulate matter, and other species (such as mercury) in a single simulation. In addition to addressing a variety of pollutants, CMAQ can be applied to a variety of regions (with varying geographical, land-use and emissions characteristics) and for a range of different space and time scales.

Numerous recent applications of the model, for both research and regulatory air quality planning purposes, have focused on the simulation of ozone and fine particulate matter ($PM_{2.5}$). The CMAQ model was used by EPA to support the development of the Clean Air Interstate Rule (CAIR) (EPA, 2005).

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation and spatial distribution of the concentrations of ozone and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. The CMAQ science algorithms are described in detail by Byun and Chang (1999(.

The CMAQ model requires several different types of input files. Gridded, hourly emission inventories characterize the release of anthropogenic, biogenic and, in some cases, geogenic emissions from sources within the modeling domain. The emissions represent both low-level and elevated sources and a variety of source categories (including, for example, point, on-road mobile, non-road mobile, area, and biogenic). The amount and spatial and temporal distribution of each emitted pollutant or precursor species are key determinants to the resultant simulated air quality values.

The CMAQ model also requires hourly, gridded input fields of several meteorological parameters including wind, temperature, mixing ratio, pressure, solar radiation, fractional cloud cover, cloud depth, and precipitation. A full list of the meteorological input parameters is given in Byun and Chang (1999). The meteorological input fields are typically prepared using a data-assimilating prognostic meteorological model, the output of which is processed for input to the CMAQ model using the Meteorology-Chemistry Interface Processor (MCIP). The prescribed meteorological conditions influence the transport, vertical mixing, and resulting distribution of the simulation pollutant

concentrations. Certain of the meteorological parameters, such as mixing ratio, can also influence the simulated chemical reaction rates. Rainfall and near-surface meteorological characteristics govern the wet and dry deposition, respectively, of the simulated atmospheric constituents.

Initial and boundary conditions (IC/BC) files provide information on pollutant concentrations throughout the domain for the first hour of the first day of the simulation, and along the lateral and top boundaries of the domain for each hour of the simulation. Photolysis rates and other chemistry related input files supply information needed by the gas-phase and particulate chemistry algorithms.

The latest available version of CMAQ, version 4.6, was used for this study. This version of the model supports several different gas-phase chemical mechanism, particle treatment, aerosol deposition, and cloud treatment options. All simulations conducted as part of this study used the CB05 chemical mechanism. For particles, the AERO4 particle treatment, which includes sea salt, was applied. For selected scenarios, the CMAQ Particle and Precursor Tagging Methodology (PPTM) (Douglas et al., 2007) was used to quantify the contribution of the emissions from selected source categories to the simulated $PM_{2.5}$ concentrations. Finally, the plume-in-grid feature of CMAQ was not used for this study.

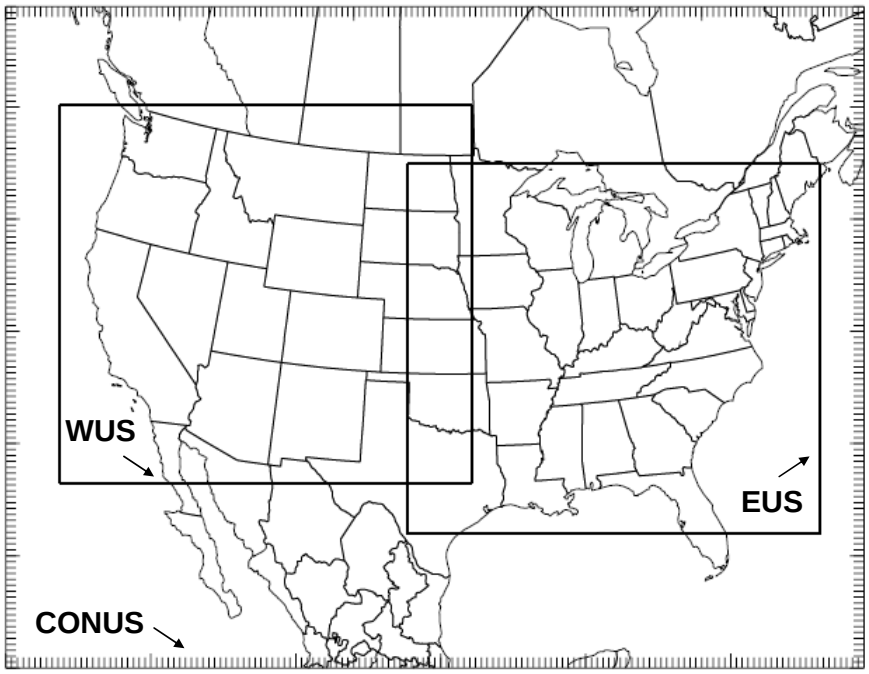
## CMAQ Application Procedures for the §812 Prospective Analysis

The application of CMAQ, including the modeling domains, simulation periods, input files (with the exception of the emission inventories), and post-processing and quality assurance procedures are discussed in this section. Preparation of the emission inventories for the application of CMAQ was discussed in detail in the previous section.

### Modeling Domains and Simulation Periods

The three modeling domains that were used for this analysis are shown in Figure IV-1.

**Figure IV-1. CMAQ Modeling Domains for the 812 Modeling Study.**



The 36-km resolution continental U.S. (CONUS) domain is the large area that is covered by the outer grid box. The CONUS domain includes 148 x 112 grid cells. The tick marks denote the 36-km grid cells. For this domain, the model was run for the entire 2002 calendar year. In running the model, the annual simulation period was divided into two parts covering January through June and July through December, respectively. Each part of the simulation also includes an additional five start-up simulation days, which are intended to reduce the influence of uncertainties in the initial conditions on the simulation results.

The Eastern U.S. (EUS) domain is comprised of 213 x 188 grid cells and the Western U.S. (WUS) domain includes 213 by 192 grid cells. Together these two domains cover most of the continental U.S. with 12-km horizontal resolution. There is some overlap in the central part of the country. For both the EUS and WUS domains, the CMAQ model was run for the months of May through September. This five-month period is intended to represent the ozone season. The seasonal simulation period was also divided into two parts covering May and June and July through September, respectively. Each part of the simulation also includes an additional ten start-up simulation days.

## Meteorological and Other Input Files

All input files for the application of the CMAQ model, with the exception of the emission inventories, were provided by EPA.

The 36- and 12-km resolution meteorological input files were prepared using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Fifth Generation Mesoscale Model (MM5). The MM5 outputs were postprocessed by EPA for input to CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) program. The meteorological input preparation methodology and some information on MM5 model performance are provided by Dolwick et al. (2007). Existing initial condition, boundary condition, land-use and photolysis rate input files prepared by EPA for use in CMAQ modeling for the selected modeling domains and simulation period were used.

## Base- and Future-Year Simulations

For each modeling domain, the CMAQ model was applied for seven core CAAA scenarios that include four different years that span a 30-year period – 1990, 2000, 2010 and 2020. As noted earlier, scenarios that incorporate the emission reductions associated with CAA are referred to as with-CAAA while those that do not are referred to as without-CAAA. The scenarios include:

Retrospective Base-Year Scenario
1990 without-CAAA

Base- and Future-Year Scenarios without 1990 CAAA Controls
2000 without-CAAA
2010 without-CAAA
2020 without-CAAA

Base- and Future-Year Scenarios with 1990 CAAA Controls
2000 with-CAAA
2010 with-CAAA
2020 with-CAAA

To aid the analysis and quality assurance of the simulation results, two additional simulations were run using the CMAQ PPTM (source apportionment/contribution) methodology. PPTM was applied for the 2010 without-CAAA and with-CAAA scenarios and for the 36-km CONUS domain. Tags were applied for the following emission source categories: 1) electric generating unit (EGU) sources in the U.S., 2) non-EGU point sources in the U.S., 3) on-road mobile sources in the U.S., 4) non-road mobile sources in the U.S., 5) all other (non-point, non-mobile) sources in the U.S. (area sources), and 6) all other sources (including natural, offshore U.S., and non-U.S. sources). An additional tag was applied to the initial and boundary conditions.

## Post-Processing and Quality Assurance Procedures

Quality assurance of the CMAQ runs included the following steps:

Scripts were routinely checked to ensure that the correct input files and output file names were used. Any error messages generated by CMAQ were check and reconciled.

Plots of ozone and selected particulate species were prepared for the 15$^{th}$ day of each month, for each simulation (each grid and each scenario). These were examined and compared with the results for other runs. The concentration patterns and values were checked for reasonableness. For each scenario, month, and each selected species, the results for the 36- and 12-km grids were compared to ensure that the differences were commensurate with those expected from differences in grid resolution. Then for each modeling domain, the results for each month and each scenario were compared to ensure that the differences among the scenarios were consistent with the emissions changes.

The CMAQ modeling results were then incorporated into ACCESS database tools, one for $PM_{2.5}$ for the CONUS domain, one for ozone for the EUS domain, and one for ozone for the WUS domain. These tools are referred as ADVISOR tools, although their functionality, especially for $PM_{2.5}$ goes well beyond that indicated by the original acronym (ACCESS$^{TM}$ Database for the Visualization and Investigation of Strategies for Ozone Reduction). The ADVISOR is an interactive database tool that contains information for review, comparison, and assessment of the CMAQ simulations. The database contains the simulation results (as represented by several different metrics) for the full domain, selected geographical subregions (EPA regions), and selected monitoring site locations. The ADVISOR database also supports application of EPA ozone and $PM_{2.5}$ attainment demonstration procedures (including the calculation of site-specific relative reduction factors and estimated design values).

For ozone, the ADVISOR metrics include daily maximum 1-hour ozone concentration (ppb), daily maximum 8-hour ozone concentration (ppb), and several ozone exposure metrics. For selected sites, relative reduction factors and estimated design values (EPA, 2007) can also be calculated and displayed.

For $PM_{2.5}$, the ADVISOR metrics include annual and quarterly average $PM_{2.5}$ concentration ($\mu gm^{-3}$), and several $PM_{2.5}$ exposure metrics. For selected sites, relative reduction factors and estimated design values (EPA, 2007) can also be calculated and displayed.

The results for all metrics can be displayed in an absolute or relative (as differences or percent differences). The ADVISOR tools were used extensive to review and compare the CMAQ results, primarily on a seasonal and annual basis.

Several examples of the types of displays that were used to review the modeling results follow.

Figure IV-2 gives two examples for $PM_{2.5}$. Figure IV-2a, presents annual $PM_{2.5}$ exceedance exposure for a threshold of 15 $\mu gm^{-3}$ for all seven scenarios. $PM_{2.5}$ exceedance exposure is defined here as the amount by which the simulated $PM_{2.5}$ concentration exceeds 15 $\mu gm^{-3}$, summed over all grid cells for a selected area and for selected simulation days. In this plot the geographic area includes the EPA Region 3 states. All simulation days are included. The calculated $PM_{2.5}$ exceedance exposure value is highest for the 2020 without-CAAA scenario and lowest for the 2020 with-CAAA scenario. The order of the scenarios indicates that, without the CAAA measures, $PM_{2.5}$ concentrations would be expected to increase with time (due to growth), and that CAAA measures will result in a decrease in $PM_{2.5}$ with time (through 2020). Figure IV-2b displays simulated annual average $PM_{2.5}$ for Pittsburgh for all scenarios. There is a sharp jump to a lower value between the without-CAAA and with-CAAA scenarios, and a more gradual increase (without-CAAA scenarios) or decrease (with-CAAA scenarios) with time.

**Figure IV-2a. Sample ADVISOR Display of Annual $PM_{2.5}$ Exceedance Exposure ($\mu gm^{-3}$) for EPA Region 3 States for the 812 Modeling Scenarios.**

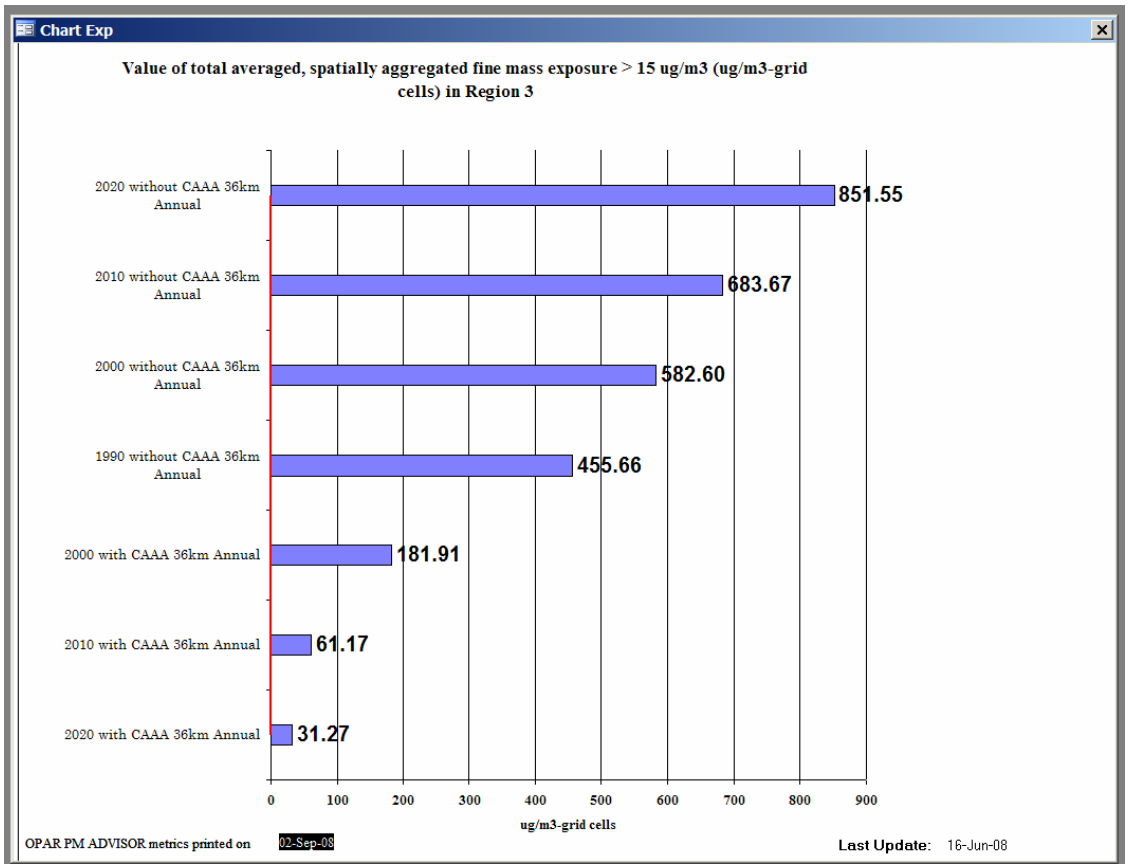


**Figure IV-2b. Sample ADVISOR Display of Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for Pittsburgh for the 812 Modeling Scenarios.**

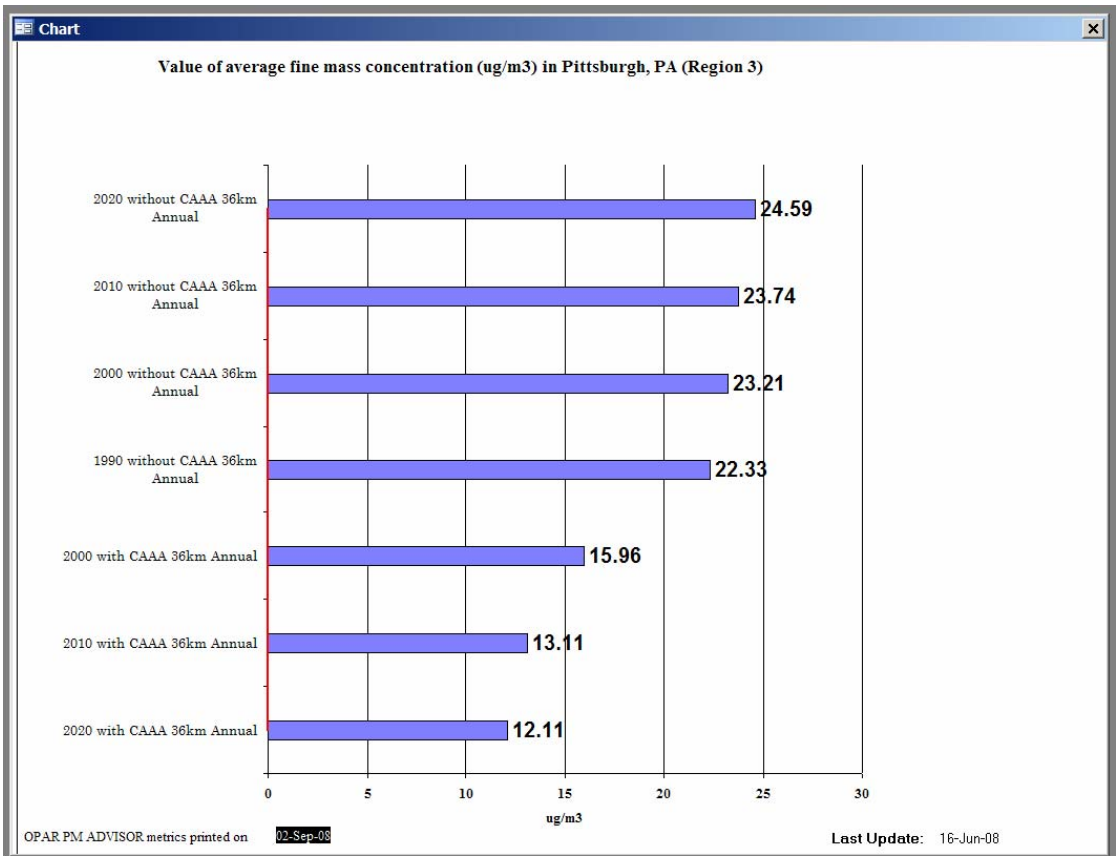



Figure IV-3 gives two examples for ozone. Figure IV-3a, presents 8-hour ozone exceedance exposure greater than 75 ppb for all scenarios and for the entire ozone season. Ozone exceedance exposure is defined here as the amount by which the simulated 8-hour ozone concentration exceeds 75 ppb, summed over all grid cells for a selected area and for selected simulation days. In this plot the geographic area includes the EPA Region 4 states. All simulation (ozone season) days are included. The calculated ozone exceedance exposure value is highest for the 2020 without-CAAA scenario and lowest for the 2020 with-CAAA scenario. The order of the scenarios indicates that without the CAAA measures ozone concentrations would be expected to increase with time (due to growth), and that CAAA measures will result in a decrease in ozone with time (through 2020). Figure IV-3b displays future-year estimated 8-hour ozone design values for Atlanta for the 2010 and 2020 scenarios. Without the CAAA measures, the design value is projected to increase (from a 2002 baseline value of 99 ppb) to 107 ppb by 2010 and to 111 ppb by 2020. When the CAAA measures are included in the modeling, the estimated design values are 86 ppb for 2010 and 74 ppb for 2020. Thus, attainment of the 8-hour ozone standard is expected by 2020.

**Figure IV-3a. Sample ADVISOR Display of 8-Hour Ozone Exceedance Exposure (ppb) for EPA Region 4 States for the 812 Modeling Scenarios.**

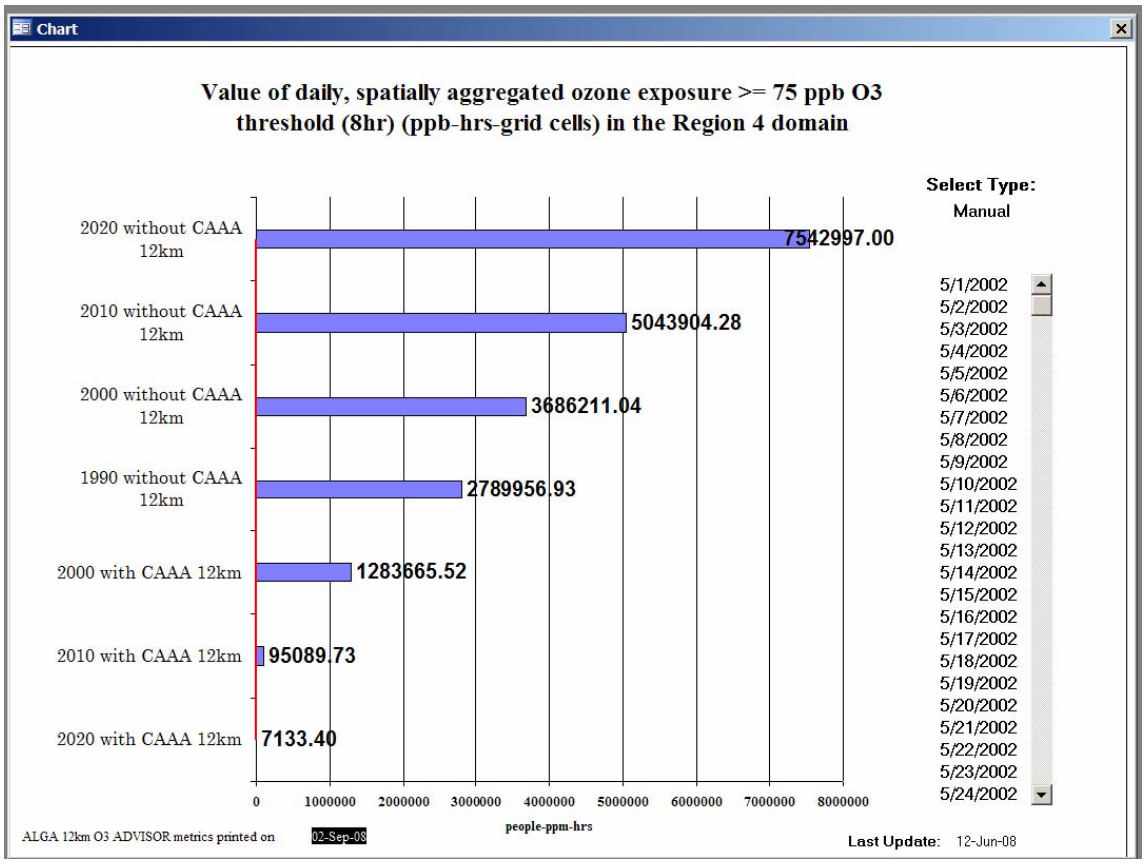
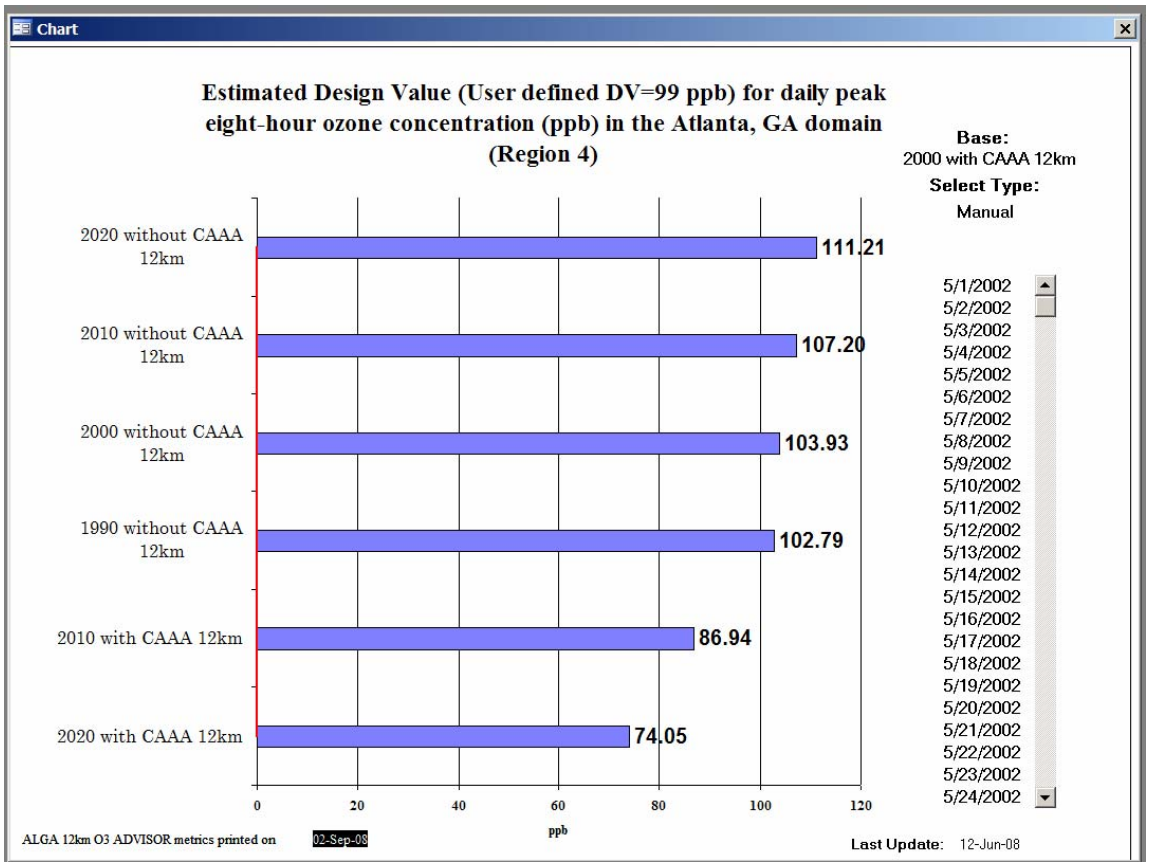


**Figure IV-3b. Sample ADVISOR Display of Future-Year 8-Hour Ozone Design Value (ppb) for Atlanta for the 2010 and 2020 812 Modeling Scenarios.**




Following the quality assurance of the modeling results, the CMAQ results were postprocessed for input to the health and ecological effects models.

## $PM_{2.5}$ and Ozone Modeling Results for the Continental U.S. Modeling Domain

This section of the report provides an overview of the CMAQ modeling results for the 36-km continental U.S. (CONUS) modeling domain. The modeling results for $PM_{2.5}$ are used for the calculation of particulate matter related health effects and to calculate visibility.

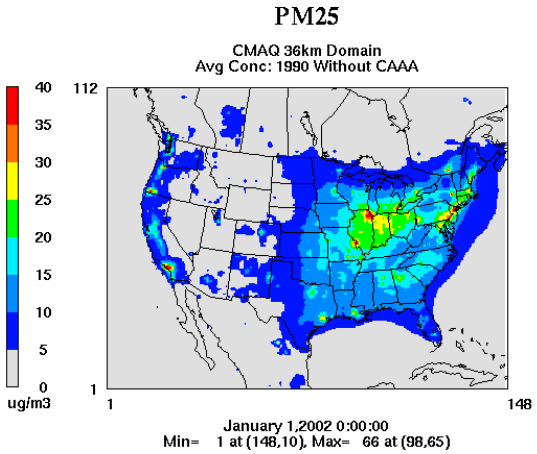
### 1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

### $PM_{2.5}$

Figure IV-4 displays simulated annual average $PM_{2.5}$ concentration ($\mu gm^{-3}$) for the CONUS domain. This plot indicates high $PM_{2.5}$ concentrations along the west coast and in the eastern U.S., with localized peak concentrations in the Los Angeles, Chicago, St. Louis, Detroit and New York urban areas. There is also an area of high $PM_{2.5}$ in southwestern Oregon. About 50 percent of the U.S. is characterized by annual average concentrations greater than the current NAAQS of 15 $\mu gm^{-3}$.

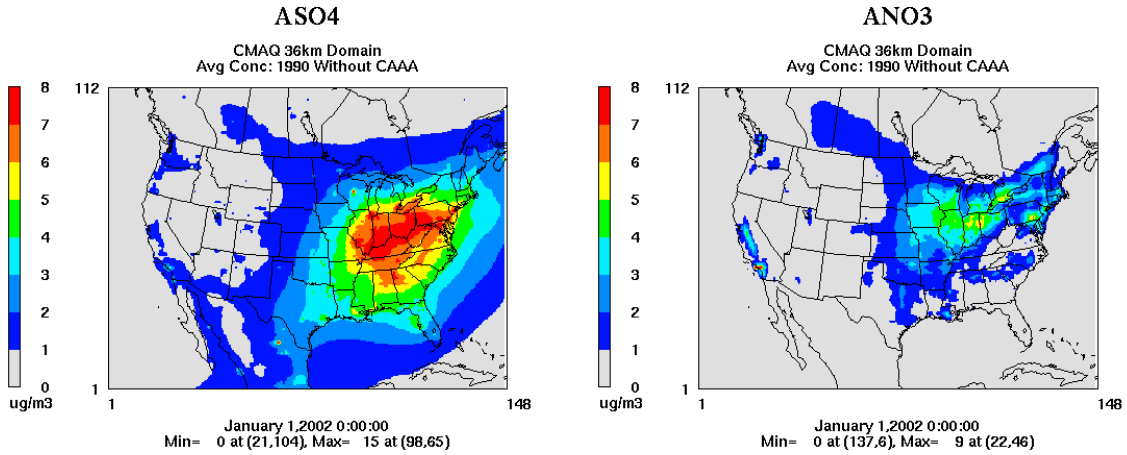
**Figure IV-4. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for the CONUS Domain: 1990 Baseline Simulation.**



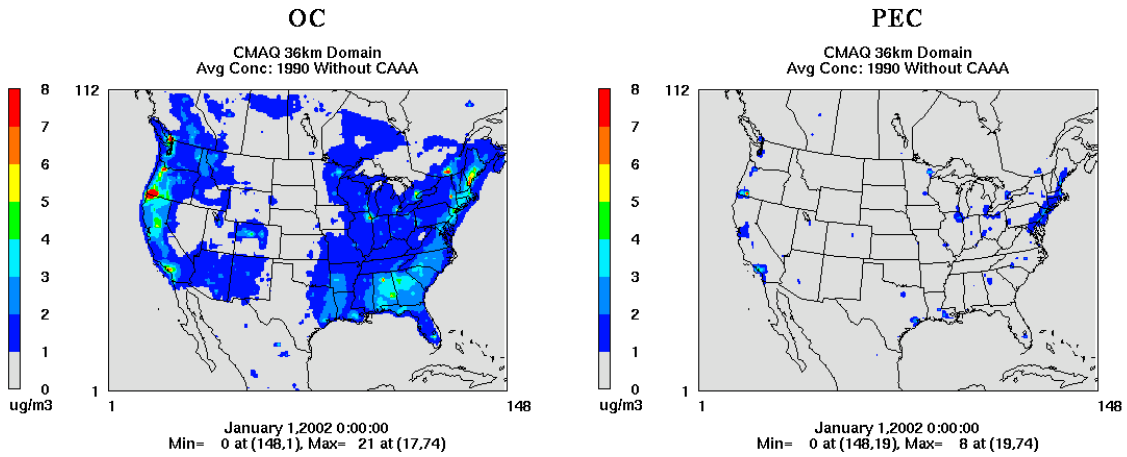

$PM_{2.5}$ is comprised of various components including sulfate, nitrate, organic carbon, and elemental carbon. These component species are plotted in Figure IV-5.

**Figure IV-5. Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain: 1990 Baseline Simulation.**

*(a) Sulfate* *(b) Nitrate*



*(c) Organic Carbon* *(d) Elemental Carbon*




For many areas, especially in the eastern U.S., sulfate (Figure IV-5a) represents the highest concentration among the component species. The geographical distribution indicated in the figure occurs partly because humidity is essential to the formation of particulate sulfate (ASO4) and sulfate does not readily form in the dryer (or arid) parts of the western U.S. It is also related to the fact that the majority of $SO_2$ is emitted from coal-fired power plants of the EGU sector and that most of these plants are located in the eastern half of the country. Organic carbon (Figure IV-5c) is also among the highest of the $PM_{2.5}$ species, especially within the urban areas. Many of the sources contributing to the formation of secondary organic aerosols (such as wood burning for home heating and cooking) are anthropogenic and related to population. Nitrate (ANO3) values (Figure 5-IVb) tend to be highest in the agricultural areas. Nitrate concentrations may derive from a number of different $NO_x$ sources including combustion, the use of nitrogen based fertilizers and livestock operations. Primary elemental carbon (PEC) comprises a relatively smaller portion of $PM_{2.5}$. PEC occurs in both urban and agricultural areas and is associated with road dust other particles caused by on-road and off-road motor vehicles.

## Ozone

Figure IV-6 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15$^{th}$ of July. This day was selected as a representative ozone-season day for display of the ozone concentrations for the 36-km domain. The ozone modeling results for the Section 812 benefits analysis were derived using 12-km horizontal resolution grids, and those results are presented in the next two sections. Ozone is shown here only to highlight relative changes in both ozone and $PM_{2.5}$ for the 36-km grid, and the multi-pollutant analysis capabilities of CMAQ.

**Figure IV-6. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 1990 Baseline Simulation.**

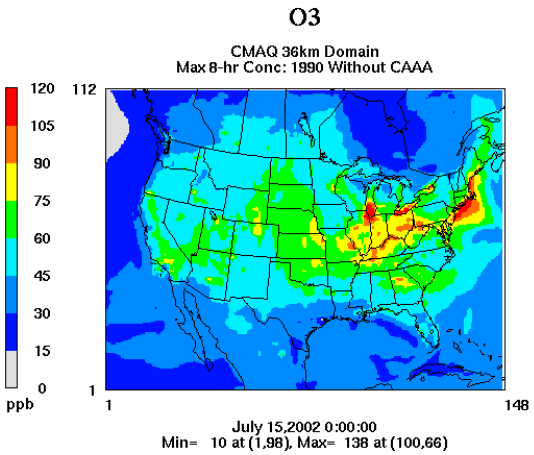



Figure IV-6 indicates that there are relative high ozone concentrations (in excess of the current 8-hour ozone NAAQS level of 75 ppb) in numerous areas throughout the U.S for this day. The highest values occur in the Midwest, along the Northeast Corridor, and in the Atlanta and Los Angeles areas. The ozone concentration pattern reflects a fairly typical summertime meteorological pattern, with an upper-level high pressure ridge over the continental U.S. and surface high pressure systems over northern Illinois and the Four Corners area. The eastern part of the nation had seasonal normal maximum temperatures around 90 degrees Fahrenheit (°F) , while the southwest, Great Basin, and upper plains experienced higher than normal temperatures, with maxima reaching from the mid-90's to over 100 °F in parts of Montana. The winds aloft over much of the U.S. were light and variable.

## Without-CAAA2000 and with-CAAA2000 Scenarios

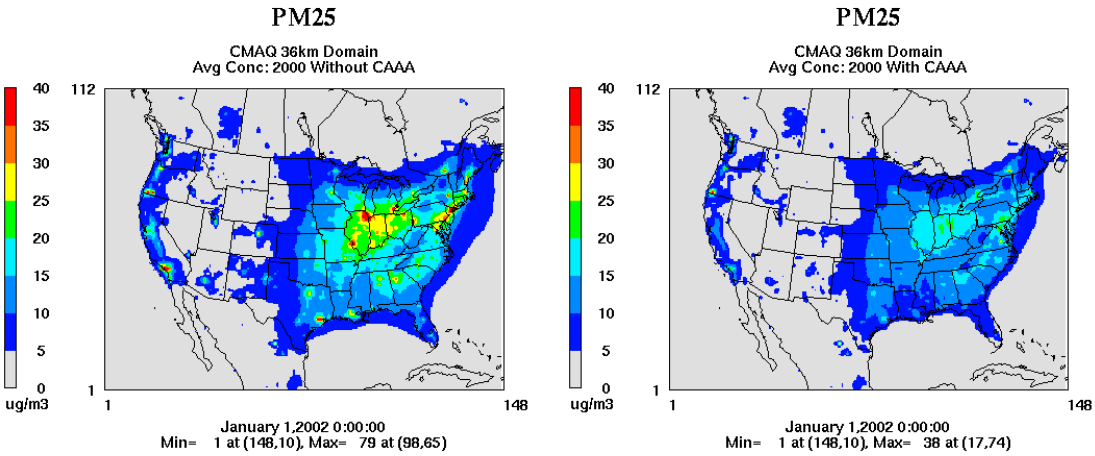
In this analysis, 2000 is the initial year for comparison of the without- and with-CAAA scenarios. The without-CAAA emissions for this year were projected from the 1990 base-year emissions. The with-CAAA emissions were based on emission inventory data for 2000. The emissions are summarized and compared in Section 2.

### $PM_{2.5}$

Figure IV-7 displays simulated annual average $PM_{2.5}$ concentration ($\mu gm^{-3}$) for the CONUS domain for the 2000 without-CAAA (Figure IV-7a) and 2000 with-CAAA (Figure IV-7b) scenarios.

**Figure IV-7. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2000 Scenarios.**

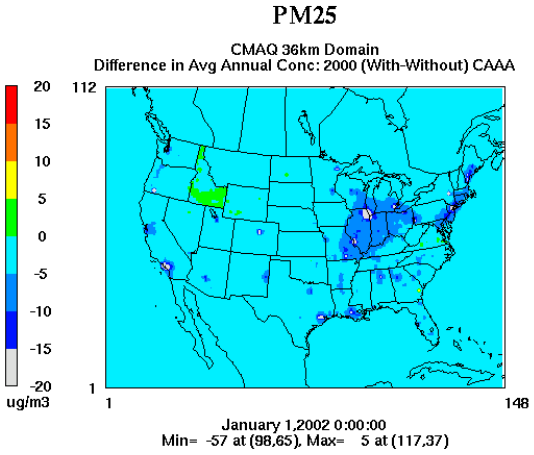
*(a) Without CAAA* *(b) With CAAA*




The areas of high concentration are reduced significantly with the CAAA measures. This is especially apparent over the Midwest, but reductions are also noticeable over the Northeast and for Los Angeles, Houston, Atlanta and several other urban areas. The domain-wide maximum simulated $PM_{2.5}$ concentration is reduced from 79 to 38 $\mu gm^{-3}$ and the location of the maximum value moves from near Chicago to southwestern Oregon.

Figure IV-8 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-8. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.**

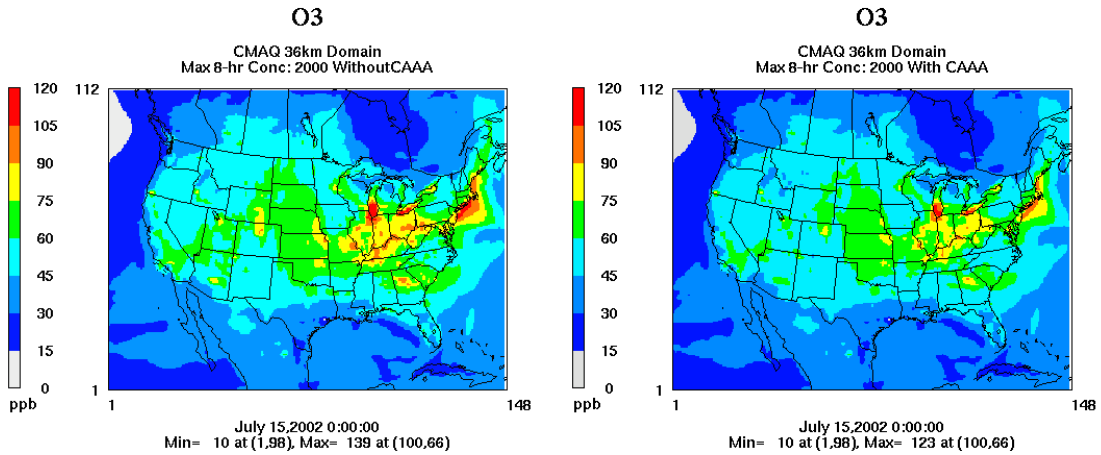



## Ozone

This same set of figures is presented for ozone. Figure IV-9 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2000 without-CAAA (Figure IV-9a) and 2000 with-CAAA (Figure IV-9b) scenarios.

**Figure IV-9. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2000 Scenarios.**

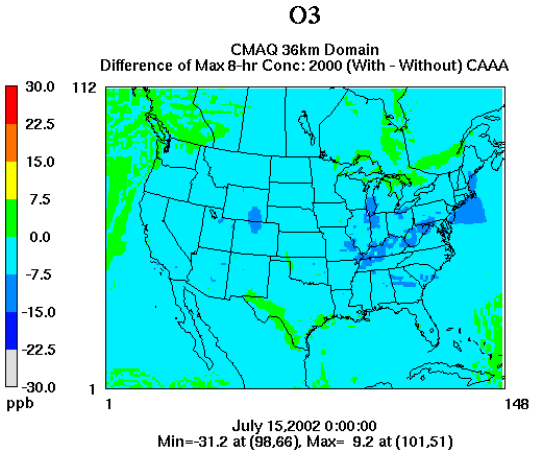
*(a) Without CAAA* *(b) With CAAA*




As with PM, there is a significant reduction in simulated ozone for 2000 with the inclusion of the CAAA measures. Reductions are notable in the Chicago and Atlanta metropolitan areas, and the Ohio River Valley and Northeast corridor areas. The peak simulated daily maximum concentration within the CONUS grid is reduced from 139 to 123 ppb in the Chicago area.

Figure IV-10 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-10. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.**




In addition to the regions mentioned above, the difference plot indicates that simulated ozone for 2000 is also reduced along the Colorado/Wyoming border and in parts of the mid-South. The daily maximum simulated 8-hour ozone concentration is reduced in the Chicago area by 31 ppb.

## Without-CAAA2010 and with-CAAA2010 Scenarios

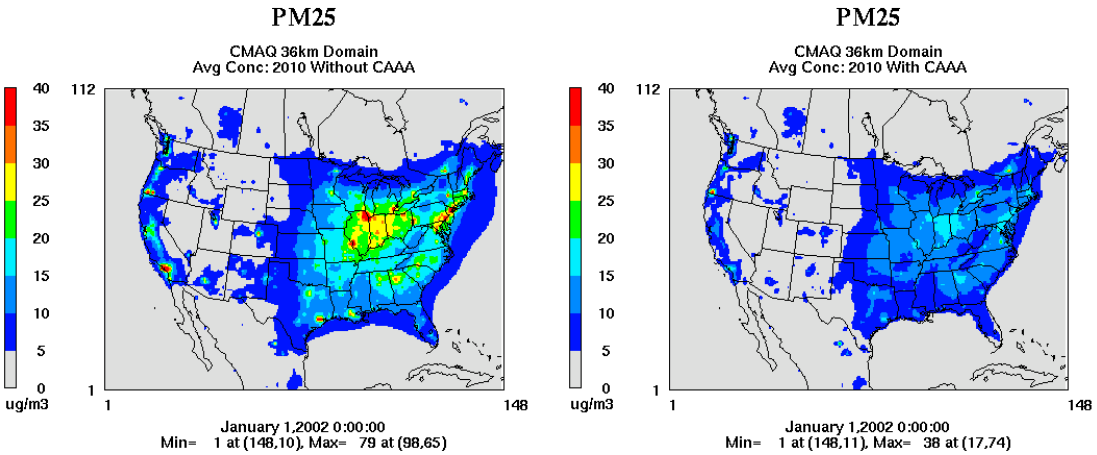
The 2010 without-CAAA emissions were projected from the 1990 base-year emissions. The 2010 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the with- and without-CAAA scenarios are greater than for 2000.

### $PM_{2.5}$

Figure IV-11 displays simulated annual average $PM_{2.5}$ concentration ($\mu gm^{-3}$) for the CONUS domain for the 2010 without-CAAA (Figure IV-11a) and 2010 with-CAAA (Figure IV-11b) scenarios.

**Figure IV-11. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2010 Scenarios.**

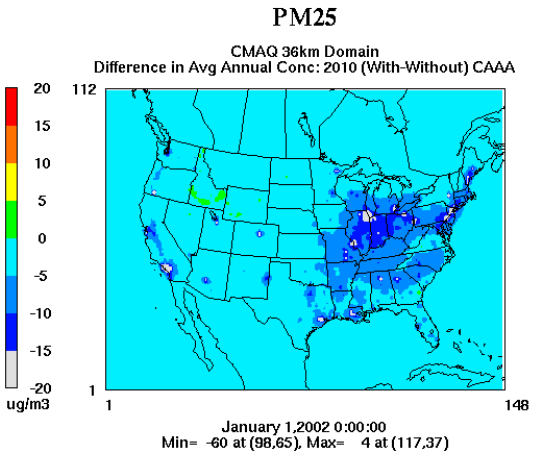
*(a) Without CAAA* *(b) With CAAA*




The reduction in annual $PM_{2.5}$ is greater than for 2000, due to increases in the without-CAAA concentrations and further decreases in the with-CAAA concentrations between 2000 and 2010. The domain-wide maximum values are unchanged compared to the 2000 scenarios.

Figure IV-12 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-12. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.**



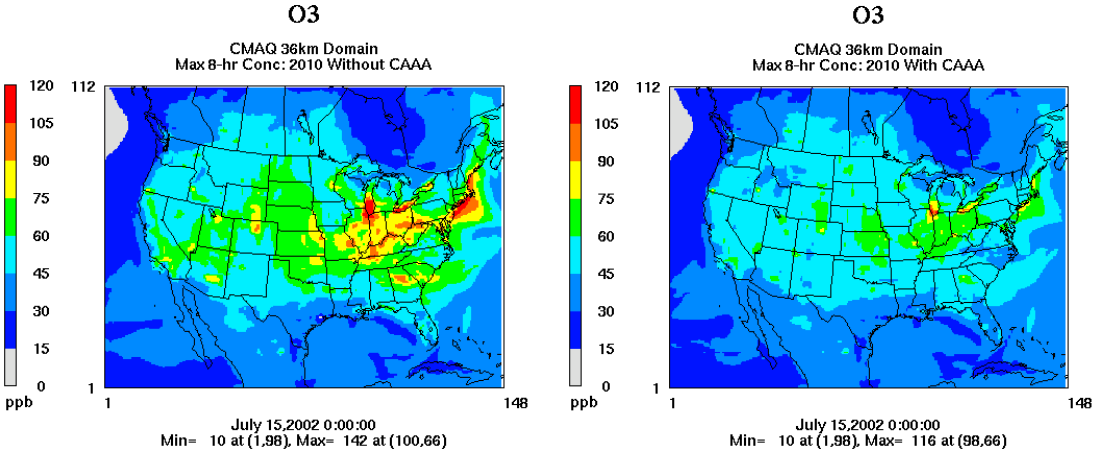

Compared to 2000, the with-CAAA reductions are greater in magnitude and cover a broader area, while the increases cover a smaller area.

## Ozone

This same set of figures is presented for ozone. Figure IV-13 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2010 without-CAAA (Figure IV-13a) and 2010 with-CAAA (Figure IV-13b) scenarios.

**Figure IV-13 Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2010 Scenarios.**

*(a) Without CAAA* *(b) With CAAA*

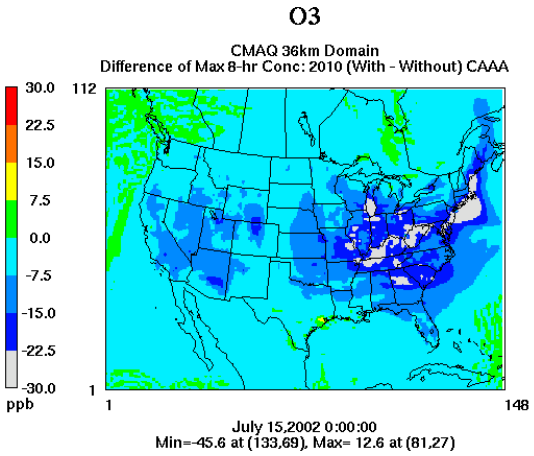



In the 2010 without-CAAA scenario, peak simulated ozone and the extent of high ozone are greater than in the 2000 without-CAAA scenario because of the expected increases in precursor emissions due to growth. The hourly peak value for the 2010 without-CAAA scenario increases

from 139 ppb in 2000 to 142 ppb in 2010. With the inclusion of CAAA controls, precursor emissions are reduced throughout the domain and resulting simulated ozone concentrations are also reduced dramatically. The peak simulated value for the 2010 with-CAAA scenario is reduced to 116 ppb in the same vicinity of the peak in the 2010 without-CAAA scenario (Chicago area).

Figure IV-14 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-14. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.**




The difference plot shows greater and more extensive reductions in simulated ozone concentrations between these scenarios compared to the year 2000 scenarios.

## Without-CAAA2020 and with-CAAA2020 Scenarios

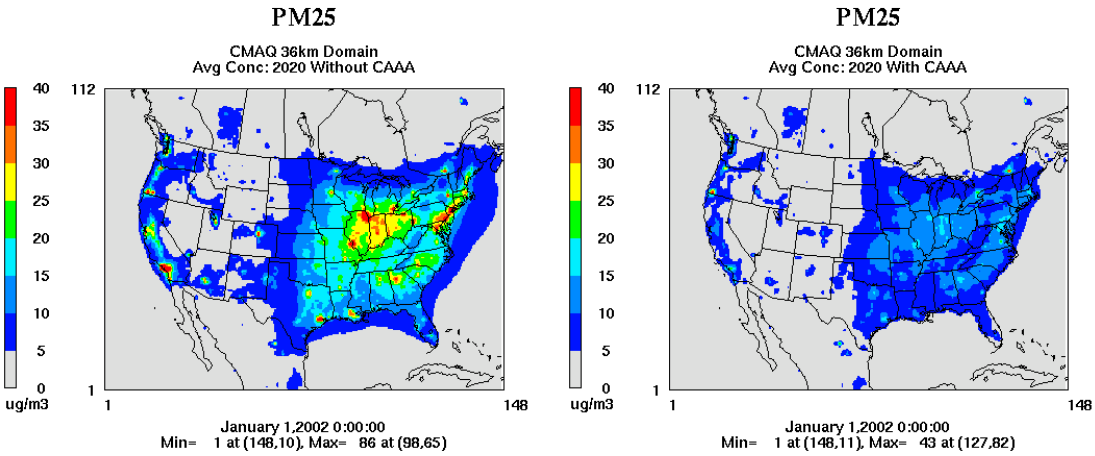
The 2020 without-CAAA emissions were projected from the 1990 base-year emissions. The 2020 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the 2020 with- and without-CAAA scenarios are greater than for the other Section 812 scenario pairs.

### $PM_{2.5}$

Figure IV-15 displays simulated annual average $PM_{2.5}$ concentration ($\mu gm^{-3}$) for the CONUS domain for the 2020 without-CAAA (Figure IV-15a) and 2020 with-CAAA (Figure IV-15b) scenarios.

**Figure IV-15. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2020 Scenarios.**

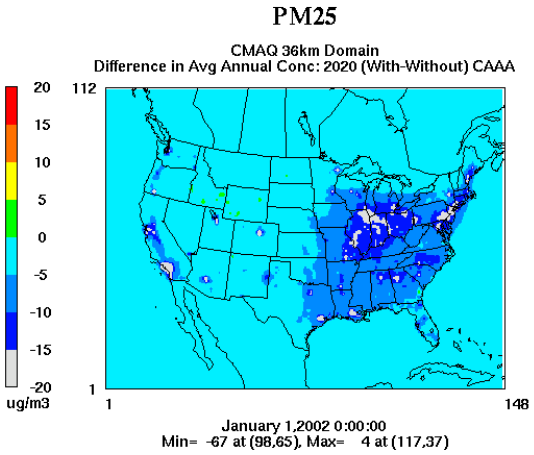
*(a) Without CAAA* *(b) With CAAA*




Compared to 2010 there are increases in the without-CAAA concentrations and further decreases in the with-CAAA concentrations. By 2020, only a few isolated areas with annual average $PM_{2.5}$ concentrations greater than 15 $\mu gm^{-3}$ remain. Again, the domain-wide maximum values do not follow this pattern – both are higher than the corresponding 2010 values.

Figure IV-16 illustrates the differences in $PM_{2.5}$ between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-16. Difference in Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.**



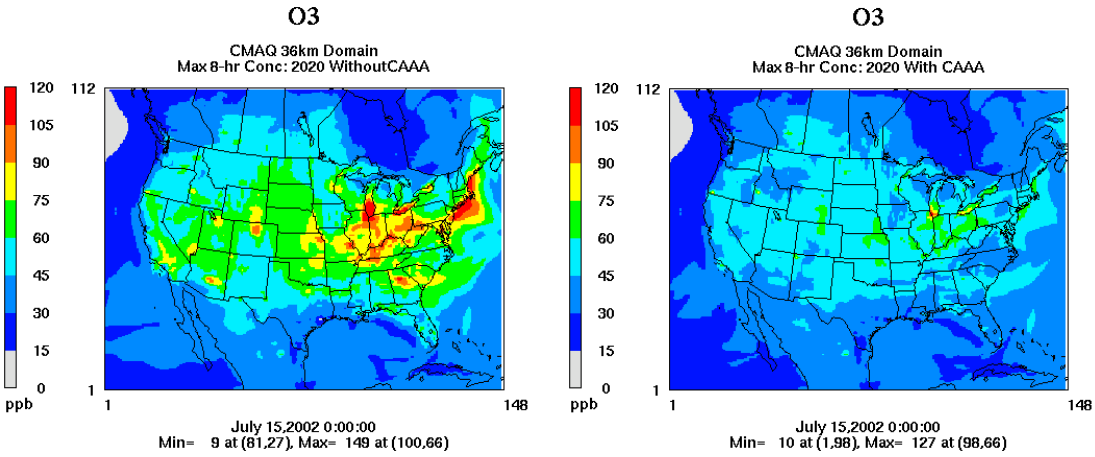

Compared to 2000 and 2010, the with-CAAA reductions are even greater in both magnitude and extent and the increases continue to shrink.

## Ozone

This same set of figures is presented for ozone. Figure IV-17 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15th of July for the 2020 without-CAAA (Figure IV-17a) and 2020 with-CAAA (Figure IV-17b) scenarios.

**Figure IV-17. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2020 Scenarios.**

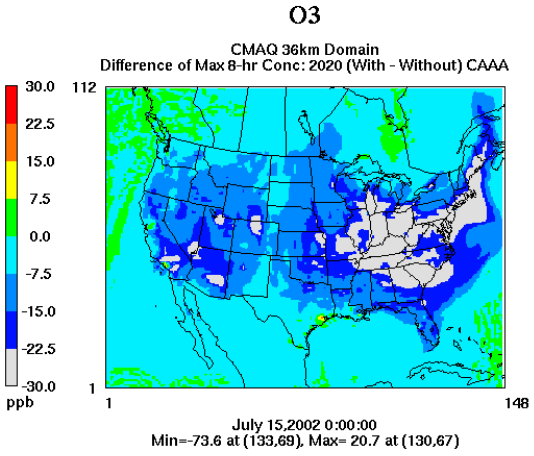
*(a) Without CAAA* *(b) With CAAA*




Compared to the 2000 and 2010 without-CAAA scenarios, the 2020 scenario shows further increases in simulated ozone, with the peak hourly simulated value increasing from 142 ppb to 149 ppb in the Chicago area. With the inclusion of CAAA controls in 2020, the magnitude and extent of high concentrations drop considerably.

Figure IV-18 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-18. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the CONUS Domain for 15 July: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.**



The ozone difference plot for the 2020 scenarios shows more extensive and larger simulated decreases in ozone throughout the modeling domain compared to the 2000 and 2010 scenarios, with a maximum reduction of 73.6 ppb for this day.

## Summary of the Effects of the CAAA on $PM_{2.5}$ Quality

Tabular summaries of the 36-km CMAQ modeling results for selected subregions and monitoring sites are presented in this section. For the 36-km domain and annual simulation period, the focus is on $PM_{2.5}$.

The subregions follow the EPA region definitions and include states within specified geographical areas of the modeling domain. The regions definitions are as follows (states are listed alphabetically for each region):

- **Region 1:** Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
- **Region 2:** New Jersey, New York
- **Region 3:** Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
- **Region 4:** Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
- **Region 5:** Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
- **Region 6:** Arkansas, Louisiana, New Mexico, Oklahoma, Texas
- **Region 7:** Iowa, Kansas, Missouri, Nebraska
- **Region 8:** Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
- **Region 9:** Arizona, California, Nevada
- **Region 10:** Idaho, Oregon, Washington

$PM_{2.5}$ monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. The monitoring sites are listed in Table IV-1.

**Table IV-1. $PM_{2.5}$ Monitoring Sites Used in the Analysis of CMAQ Results for the 812 Modeling Study.**

| Region | Site Location |
|---|---|
| Region 1 | New Haven, CT |
| | Boston, MA |
| | Portsmouth, NH |
| Region 2 | New Brunswick, NJ |
| | Bronx, NY (New York City) |
| Region 3 | Fort Meade, MD (Baltimore) |
| | Philadelphia, PA |
| | Pittsburgh, PA |
| | Richmond, VA |
| Region 4 | Pensacola, FL |
| | Atlanta, GA |
| | Charlotte, NC |
| | Knoxville, TN |
| | Memphis, TN |

| Region | Site Location |
|---|---|
| Region 5 | Chicago, IL |
| | Minneapolis, MN |
| | Cleveland, OH |
| | Milwaukee, WI |
| Region 6 | Baton Rouge, LA |
| | Albuquerque, NM |
| | Dallas, TX |
| | Houston, TX |
| Region 7 | Kansas City, KS |
| | St Louis, MO |
| Region 8 | Commerce City, CO (Denver) |
| | Missoula, MT |
| | Salt Lake City, UT |
| Region 9 | Phoenix, AZ |
| | Sacramento, CA |
| | Fresno, CA |
| | Bakersfield, CA |
| | Los Angeles, CA |
| Region 10 | Boise, ID |
| | Seattle, WA |

Several metrics are used to summarize the modeling results for $PM_{2.5}$, including annual average $PM_{2.5}$, annual $PM_{2.5}$ exceedance exposure for a threshold of 15 $\mu gm^{-3}$, and estimated design value. These metrics were defined previously in this report.

Table IV-2 lists the annual $PM_{2.5}$ exceedance exposure for each subregion and scenario.

**Table IV-2. $PM_{2.5}$ Exceedance Exposure Based on 15 μgm-3 for all Section 812 Scenarios.**

*Units are μgm-3 * grid cell * days.*

| Region | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| Region 1 | 239 | 239 | 23 | 253 | 9 | 289 | 3 |
| Region 2 | 269 | 277 | 32 | 299 | 4 | 354 | 0 |
| Region 3 | 456 | 583 | 182 | 684 | 61 | 852 | 31 |
| Region 4 | 596 | 1125 | 102 | 1489 | 24 | 1979 | 9 |
| Region 5 | 2498 | 3044 | 610 | 3272 | 78 | 3795 | 15 |
| Region 6 | 205 | 390 | 15 | 501 | 5 | 905 | 6 |
| Region 7 | 444 | 632 | 24 | 726 | 10 | 979 | 8 |
| Region 8 | 7 | 34 | 0 | 49 | 0 | 93 | 0 |
| Region 9 | 130 | 157 | 15 | 244 | 14 | 462 | 15 |
| Region 10 | 85 | 99 | 30 | 114 | 35 | 171 | 39 |

For most regions, this metric is characterized by a steady increase with time for the without-CAAA scenarios, with the greatest increases between 2010 and 2020. Conversely, $PM_{2.5}$ exceedance exposure typically decreases with time for the with-CAAA scenarios. For all regions, the greatest decrease occurs between 1990 and 2000. For some regions, this relatively large reduction is followed by a small increase for 2010, 2020 or both years, presumably due to growth.

Table IV-3 lists the simulated annual $PM_{2.5}$ concentration for each monitoring site and scenario.

**Table IV-3. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu gm^{-3}$) for Selected Monitoring Sites and all Section 812 Scenarios.**

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| **Region 1 Sites** | | | | | | | |
| New Haven, CT | 22.8 | 23.0 | 14.6 | 23.4 | 13.0 | 25.0 | 11.6 |
| Boston, MA | 21.8 | 21.8 | 15.9 | 22.3 | 14.5 | 23.6 | 13.3 |
| Portsmouth, NH | 19.5 | 19.8 | 11.4 | 20.3 | 10.5 | 20.9 | 9.7 |
| **Region 2 Sites** | | | | | | | |
| New Brunswick, NJ | 41.9 | 38.8 | 20.2 | 40.3 | 16.9 | 43.4 | 15.1 |
| Bronx, NY (New York City) | 50.8 | 50.5 | 22 | 51.8 | 18.3 | 55.8 | 16.1 |
| **Region 3 Sites** | | | | | | | |
| Fort Meade, MD (Baltimore) | 29.1 | 31.3 | 21.5 | 32.7 | 19.4 | 36 | 18.5 |
| Philadelphia, PA | 34.3 | 35.3 | 19.4 | 37 | 16.7 | 40.2 | 15.2 |
| Pittsburgh, PA | 22.3 | 23.2 | 16 | 23.7 | 13.1 | 24.6 | 12.1 |
| Richmond, VA | 16.1 | 17.6 | 16.8 | 18.8 | 15 | 20.3 | 14.2 |
| **Region 4 Sites** | | | | | | | |
| Pensacola, FL | 16.5 | 17.8 | 13.6 | 18.8 | 13.7 | 19.9 | 14 |
| Atlanta, GA | 21.7 | 24.7 | 18.2 | 26.6 | 16.5 | 29.2 | 15.2 |
| Charlotte, NC | 17.7 | 20 | 15.6 | 21.6 | 13.1 | 23.6 | 11.7 |
| Knoxville, TN | 15.5 | 16.8 | 13.4 | 17.7 | 11.5 | 18.7 | 10.1 |
| Memphis, TN | 15.6 | 16.8 | 12.6 | 17.2 | 10.9 | 18.2 | 10.2 |
| **Region 5 Sites** | | | | | | | |
| Chicago, IL | 66.5 | 78.6 | 21.2 | 79.3 | 18.9 | 85.5 | 18.4 |
| Minneapolis, MN | 23.7 | 26.4 | 16.3 | 27.7 | 15.5 | 30.5 | 15.4 |
| Cleveland, OH | 23.7 | 26 | 17.4 | 26.6 | 13.9 | 27.8 | 12.3 |
| Milwaukee, WI | 23.7 | 26 | 15.6 | 26.2 | 14.4 | 28.1 | 13.8 |
| **Region 6 Sites** | | | | | | | |
| Baton Rouge, LA | 15.6 | 17 | 10.7 | 17.7 | 9.8 | 20.5 | 9.6 |
| Albuquerque, NM | 13.8 | 14.9 | 10.4 | 14.8 | 10 | 15.8 | 10 |
| Dallas, TX | 23.8 | 29.3 | 18.5 | 30 | 17 | 33.3 | 16.9 |
| Houston, TX | 25.5 | 29.5 | 14.3 | 30.2 | 14.2 | 33.2 | 14.9 |
| **Region 7 Sites** | | | | | | | |
| Kansas City, KS | 20.2 | 21.7 | 15.1 | 22.5 | 13.8 | 24.1 | 13.3 |
| St Louis, MO | 52.5 | 62.8 | 20.9 | 65.3 | 18.7 | 71.9 | 18.3 |

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| **Region 8 Sites** | | | | | | | |
| Commerce City, CO (Denver) | 20.3 | 28.7 | 11.1 | 31.6 | 11.2 | 39.9 | 12 |
| Missoula, MT | 4.5 | 4.7 | 4 | 4.8 | 3.9 | 5.1 | 3.9 |
| Salt Lake City, UT | 13.4 | 18.3 | 8.9 | 20.5 | 8.9 | 25.7 | 9.4 |
| **Region 9 Sites** | | | | | | | |
| Phoenix, AZ | 16 | 23.7 | 10.2 | 27 | 9.9 | 34.7 | 10.7 |
| Sacramento, CA | 16.2 | 16.1 | 11.4 | 17.5 | 11 | 20.8 | 10.9 |
| Fresno, CA | 15 | 14.8 | 10.7 | 16.5 | 9.5 | 20 | 9.7 |
| Bakersfield, CA | 12.7 | 12.7 | 9.4 | 13.8 | 8.4 | 17.9 | 10.4 |
| Los Angeles, CA | 27.8 | 29.5 | 13.3 | 33.9 | 12.4 | 42.7 | 12.4 |
| **Region 10 Sites** | | | | | | | |
| Boise, ID | 5.9 | 6.6 | 6 | 7.4 | 6 | 8.6 | 6.2 |
| Seattle, WA | 16.7 | 17 | 11.8 | 18.6 | 12.6 | 21.9 | 13.6 |

Simulated annual average $PM_{2.5}$ concentrations generally increase with time for the without-CAAA scenarios, and decrease with time for the with-CAAA scenarios. As for the exposure metric, with the greatest increases for the without-CAAA scenarios occur between 2010 and 2020 and the greatest decreases for the with-CAAA scenarios occur between 1990 and 2000. There are some future-year increases in concentration at the site locations for the with-CAAA scenarios, especially for western sites for 2020.

Table IV-4 presents the estimated future-year $PM_{2.5}$ design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation based) design value. Quarterly and species-specific model-derived relative reduction factors were applied to observation-based average quantities in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 15 $\mu gm^{-3}$ is an indicator of future-year attainment.

**Table IV-4. Estimated Future-Year $PM_{2.5}$ Design Value ($\mu gm^{-3}$) for Selected Monitoring Sites and the Future-Year Section 812 Scenarios.**

| | 2002 DV | 2010 w/o CAAA | 2010 w/CAAA | 2020 w/o CAAA | 2020 w/CAAA |
|---|---|---|---|---|---|
| **Region 1 Sites** | | | | | |
| New Haven, CT | 16.5 | 24.1 | 13.6 | 25.0 | 12.4 |
| Boston, MA | 13.0 | 17.1 | 11.5 | 17.6 | 10.9 |
| Portsmouth, NH | 11.2 | 19.6 | 9.8 | 19.9 | 9.2 |
| **Region 2 Sites** | | | | | |
| New Brunswick, NJ | 12.7 | 22.0 | 10.6 | 23.0 | 9.9 |
| Bronx, NY (New York City) | 14.2 | 26.3 | 12.0 | 27.7 | 11.2 |

| | 2002 DV | 2010 w/o CAAA | 2010 w/CAAA | 2020 w/o CAAA | 2020 w/CAAA |
|---|---|---|---|---|---|
| **Region 3 Sites** | | | | | |
| Fort Meade, MD (Baltimore) | 14 | 19.7 | 11.6 | 20.7 | 10.7 |
| Philadelphia, PA | 15.4 | 24.9 | 12.9 | 26.1 | 11.9 |
| Pittsburgh, PA | 15.8 | 23 | 12 | 23.5 | 10.8 |
| Richmond, VA | 14 | 17.3 | 11.3 | 17.8 | 10.1 |
| **Region 4 Sites** | | | | | |
| Pensacola, FL | 12.1 | 17.4 | 11.2 | 17.7 | 10.6 |
| Atlanta, GA | 16.5 | 23.3 | 14.2 | 24.2 | 12.2 |
| Charlotte, NC | 15.1 | 20.3 | 12.2 | 20.8 | 10.4 |
| Knoxville, TN | 17.3 | 23.8 | 14.3 | 24.1 | 12 |
| Memphis, TN | 14.9 | 21.6 | 12.6 | 22.4 | 11.6 |
| **Region 5 Sites** | | | | | |
| Chicago, IL | 16.3 | 64.8 | 14.6 | 67 | 14.5 |
| Minneapolis, MN | 10.9 | 16.6 | 10.7 | 18 | 10.8 |
| Cleveland, OH | 18.2 | 28.8 | 14.4 | 29.7 | 13.3 |
| Milwaukee, WI | 12.7 | 21.1 | 11.9 | 21.8 | 11.7 |
| **Region 6 Sites** | | | | | |
| Baton Rouge, LA | 13.6 | 21.9 | 12.1 | 25.6 | 11.6 |
| Albuquerque, NM | 6.4 | 8.8 | 6.2 | 9.7 | 6.3 |
| Dallas, TX | 12.6 | 18.9 | 11.3 | 20.6 | 11.1 |
| Houston, TX | 14.1 | 26.9 | 13.5 | 29.4 | 13.9 |
| **Region 7 Sites** | | | | | |
| Kansas City, KS | 13.5 | 18.8 | 12.4 | 19.6 | 12.1 |
| St Louis, MO | 15.7 | 32.6 | 14.1 | 34.6 | 13.9 |
| **Region 8 Sites** | | | | | |
| Commerce City, CO (Denver) | 10.3 | 21.8 | 10.2 | 26.6 | 10.5 |
| Missoula, MT | 11.4 | 12.8 | 11.1 | 13.6 | 11.1 |
| Salt Lake City, UT | 12 | 22.1 | 12.1 | 26.5 | 12.8 |
| **Region 9 Sites** | | | | | |
| Phoenix, AZ | 10.8 | 22.3 | 10.7 | 27.9 | 11.6 |
| Sacramento, CA | 11.1 | 13.8 | 10.8 | 15.8 | 10.9 |
| Fresno, CA | 21.9 | 26.2 | 19.5 | 30.5 | 20 |
| Bakersfield, CA | 22.1 | 27.6 | 20 | 35.1 | 25.6 |
| Los Angeles, CA | 22.2 | 43.1 | 20.4 | 52.7 | 22.8 |
| **Region 10 Sites** | | | | | |
| Boise, ID | 9.9 | 11.7 | 10 | 13.2 | 10.6 |
| Seattle, WA | 8.8 | 11.6 | 9.2 | 13.2 | 10.3 |

Estimated $PM_{2.5}$ design values increase with time for the without-CAAA scenarios. For a majority of the sites, the estimated design values for both 2010 and 2020 are greater than 15 $\mu gm^{-3}$ for the without-CAAA scenarios.

For most sites the estimated design values decrease with time for the with-CAAA scenarios, but the results are mixed. There are several sites for which the estimated design values increase slightly between 2002 and 2010, and several more for which the design values increase between 2010 and 2020. The increases do not change the expectations for attainment at any of the sites. The estimated design values for both 2010 and 2020 are less than 15 $\mu gm^{-3}$ for all but three sites (Fresno, Bakersfield and Los Angeles, CA). These three sites have very high base-year design values and the future-year design values for both Bakersfield and Los Angeles consistently increase rather than decrease with time, even with the CAAA measures.

The results are qualitatively similar for all three metrics. The CMAQ results for 2002 are characterized by relatively low $PM_{2.5}$ concentrations compared to the design values at several western sites. Thus, the estimated design value calculations which combine the modeling results and the observed data are an important tool for the overall assessment of the effects of the CAAA relative to attainment of the $PM_{2.5}$ NAAQS.

## $PM_{2.5}$ Source Contribution Analysis for 2010

Within CMAQ, the Ozone and Precursor Tagging Methodology (OPTM) and the Particle and Precursor Tagging Methodology (PPTM) are designed to provide detailed, quantitative information about the *contribution* of selected sources, source categories, and/or source regions to simulated ozone and $PM_{2.5}$ concentrations, respectively. Emissions of precursor pollutants from selected sources, source categories, or source regions are (numerically) tagged and then tracked throughout a simulation. The contribution from each tag to the resulting simulated concentration of ozone, $PM_{2.5}$, or any of the $PM_{2.5}$ component species for any given location within the CMAQ modeling domain can be quantified. By tracking the emissions from selected sources or source locations, the methodology also provides information on the fate of the emissions from these sources.

The tagging methodology differs from the use of air quality model sensitivity simulations in which the emissions are modified or eliminated (zeroed-out). Sensitivity simulations typically provide information about the effects of changes in the emissions on the simulation results. In contrast, tagging provides information about the contribution of the emissions from the tagged sources, relative to the unmodified simulated conditions. Identifying and quantifying source contributions from certain sources or source sectors can inform air quality planning and aid the assessment of control measures.

CMAQ/PPTM was used in this study to examine the contributions of emissions from the major source categories to simulated $PM_{2.5}$ concentrations and to quantify the changes in these contributions between the with- and without-CAAA scenarios. The application of PPTM was limited to 2010 and was used primarily for quality assurance purposes – to assess whether the changes in concentrations were consistent with the changes in emissions. However, the PPTM results also provide some interesting information about which sources contribute to the simulated $PM_{2.5}$ concentrations, how the source contributions differ between the without- and with-CAAA scenarios, and, consequently, the relative effectiveness of the source-category specific CAAA measures in reducing $PM_{2.5}$ concentrations.

### Technical Description of PPTM

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation, and spatial distribution of the concentrations of ozone and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. Within the model, tagging is accomplished by the addition of duplicate model species variables for each source, source

category, or source region that is to be tagged. For PPTM, the duplicated species include all PM-related sulfur, nitrogen, and secondary organic compounds, as well as primary organic carbon, elemental carbon, and other inorganic particulates.[1] The tagged species have the same properties and are subjected to the same processes (e.g., advection, chemical transformation, deposition) as the actual (or base) species. Because the tagged species are separate from the base species, tagging does not alter or affect the base simulation results.

PPTM was developed to utilize model algorithms as much as possible to track simulated tagged species concentrations. Processes that are linear, or not species-specific, utilize the model algorithms to calculate the changes in species concentrations. An example of this type of process is advection. Other processes that are potentially non-linear or involve interactions with other species, are given a special treatment and are calculated for the overall (or base) species and apportioned to the tagged species. An example of this type of process is aqueous-phase chemistry.

PPTM includes a species-specific approach for each reactive species (sulfur, nitrogen, and secondary organic compounds) and a more general approach for the non-reactive species (primary organic carbon, elemental carbon, and other inorganic particulates).

### PPTM Application Procedures for the §812 Modeling Analysis

CMAQ/PPTM simulations were conducted using the 2010 without-CAAA and the 2010 with-CAAA emissions inventories. The simulations were run for the 36- km CONUS modeling domain.

For each scenario, PPTM was use to examine the contributions to simulated PM for the following major emissions source categories:

- EGU sources in the U.S.
- Non-EGU point sources in the U.S.
- On-road mobile sources in the U.S.
- Non-road mobile sources in the U.S.
- Area (non-point, non-mobile) sources in the U.S.
- Initial and boundary conditions (IC/BCs)
- All other sources (including natural emissions, U.S. offshore sources, and non-U.S. sources)

### Source-Contribution Analysis Results

Selected plots of the PPTM results are shown in Figure IV-19. The contribution to annual average $PM_{2.5}$ from each of the seven tagged source category tags is displayed in Figure IV-19 for both the without- and with-CAAA scenarios.

[1] For OPTM, the duplicated modeled species are ozone, nitrogen oxides ($NO_x$), and volatile organic compounds (VOCs).

**Figure IV-19a. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from EGU Sources in the U.S.**

*(a) Without CAAA* *(b) With CAAA*

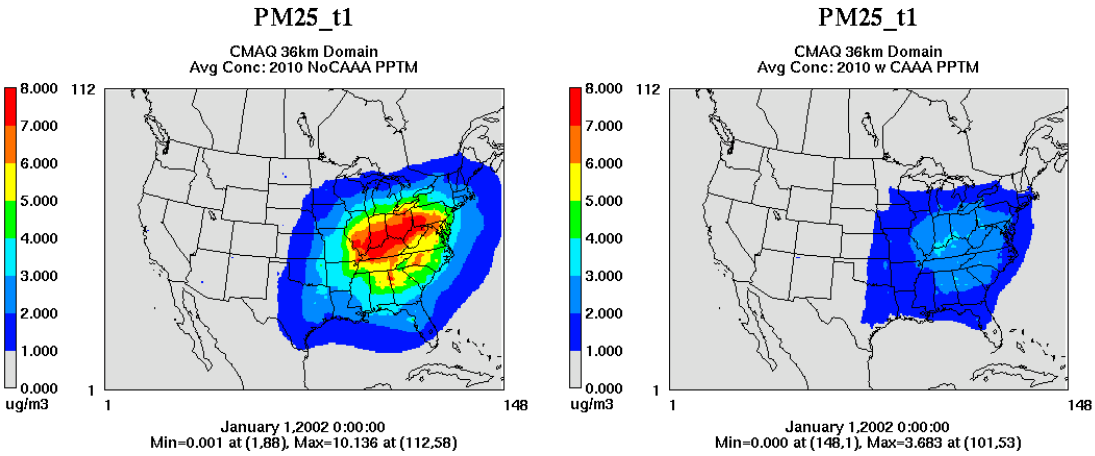



**Figure IV-19b. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from Non-EGU Sources in the U.S.**

*(a) Without CAAA* *(b) With CAAA*

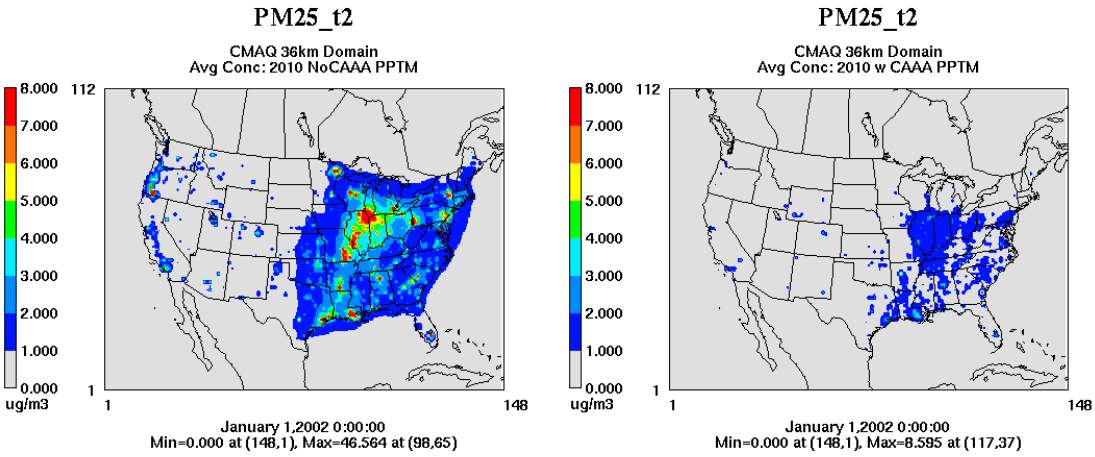


**Figure IV-19c. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from On-Road Mobile Sources in the U.S.**

*(a) Without CAAA* *(b) With CAAA*

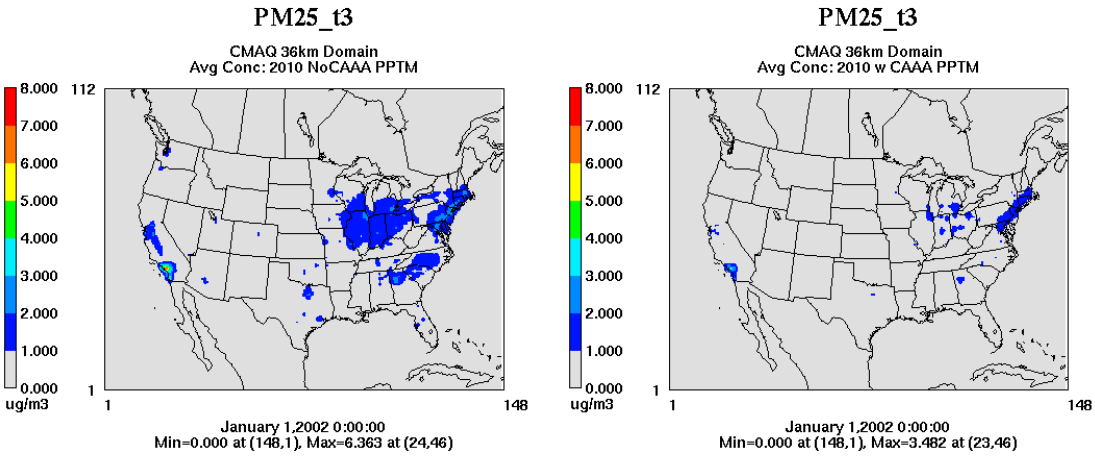



**Figure IV-19d. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from Non-Road Sources in the U.S.**

*(a) Without CAAA* *(b) With CAAA*

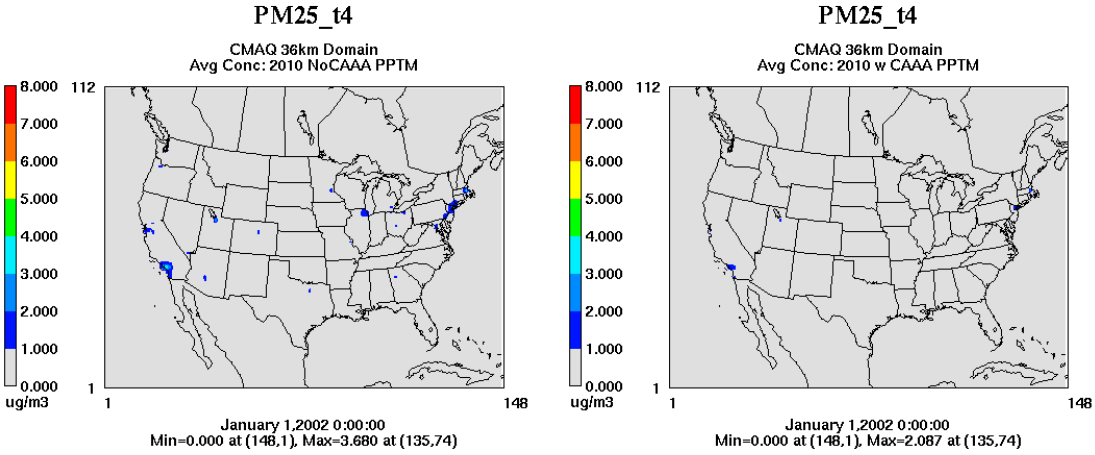


**Figure IV-19e. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from Area Sources in the U.S.**

*(a) Without CAAA* *(b) With CAAA*

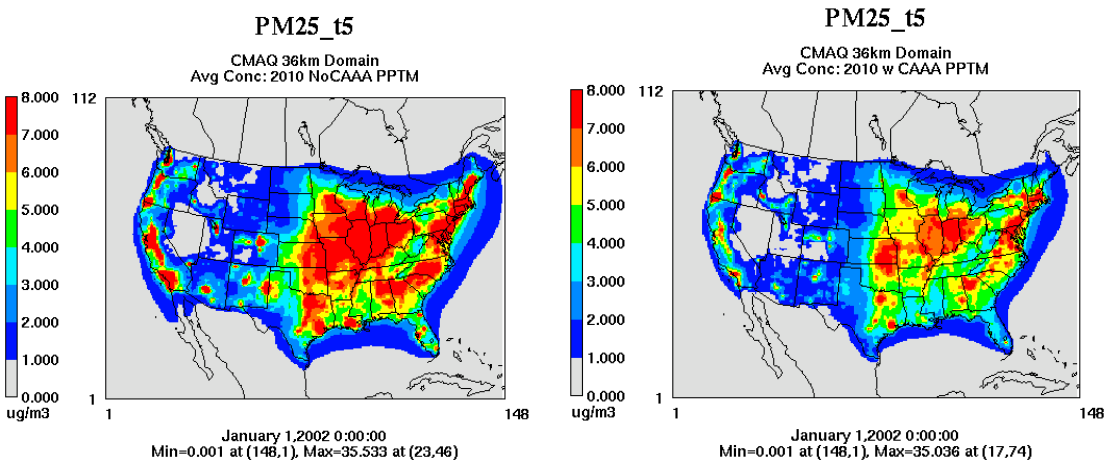



**Figure IV-19f. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Initial and Boundary Conditions.**

*(a) Without CAAA* *(b) With CAAA*

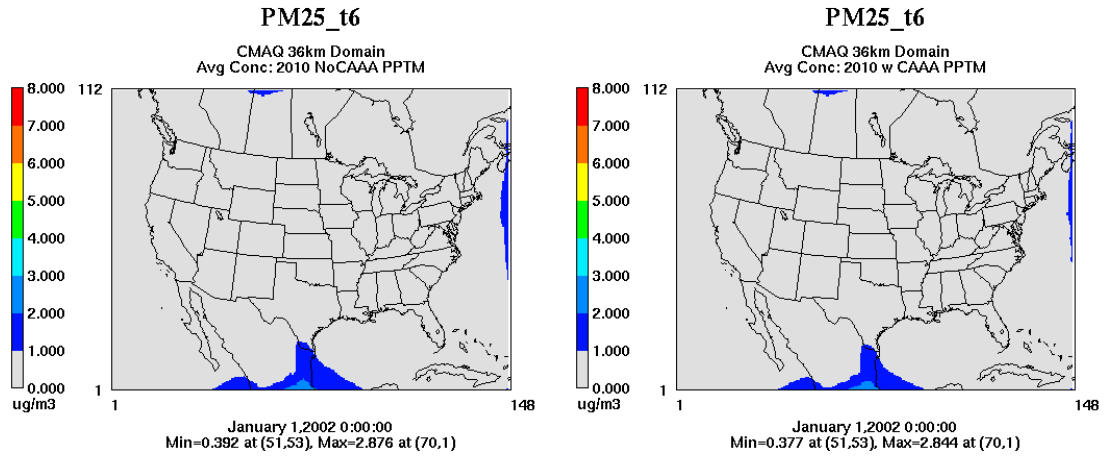
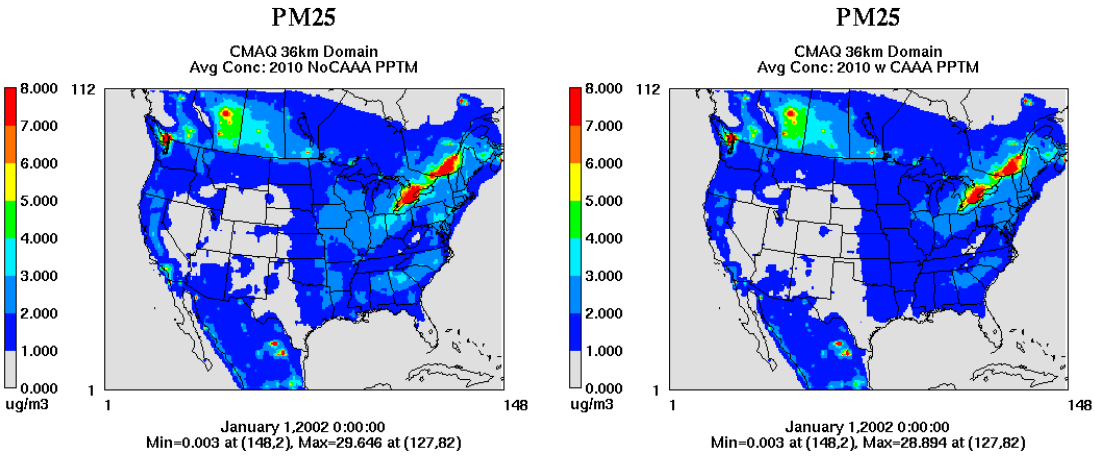


**Figure IV-19g. Contribution to Simulated Annual Average $PM_{2.5}$ Species Concentration ($\mu gm^{-3}$) for the CONUS Domain from Emissions from All Other Sources.**

*(a) Without CAAA* *(b) With CAAA*

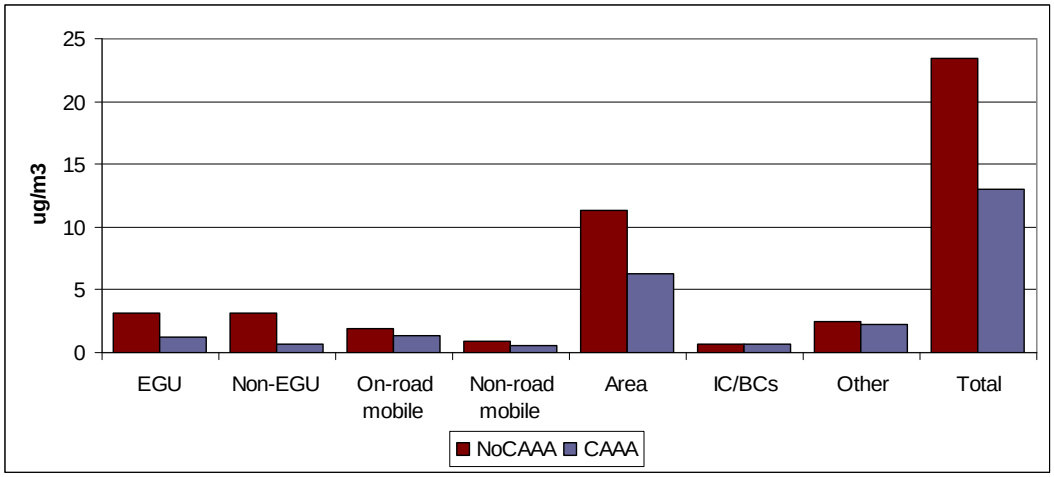



For most of the tagged source categories the contributions are much lower for the with-CAAA scenario. The overall effects of the CAAA measures on the simulated contributions vary by source category in accordance with the control measures for that category. For example, Figure IV-19a shows that the contribution from EGU emissions is substantially lower for 2010 for the with-CAAA scenario, particularly over the eastern U.S. This is due to lower $NO_x$, $SO_2$, and $PM_{2.5}$ emissions from coal-fired utility sources under the CAAA. The simulated contributions from emissions from non-EGU point sources (Figure IV-19b) and area sources (Figure IV-19e) are also substantially lower under the with-CAAA scenario. Emissions from these three categories comprise the largest contributions to the simulated annual average $PM_{2.5}$ concentrations.

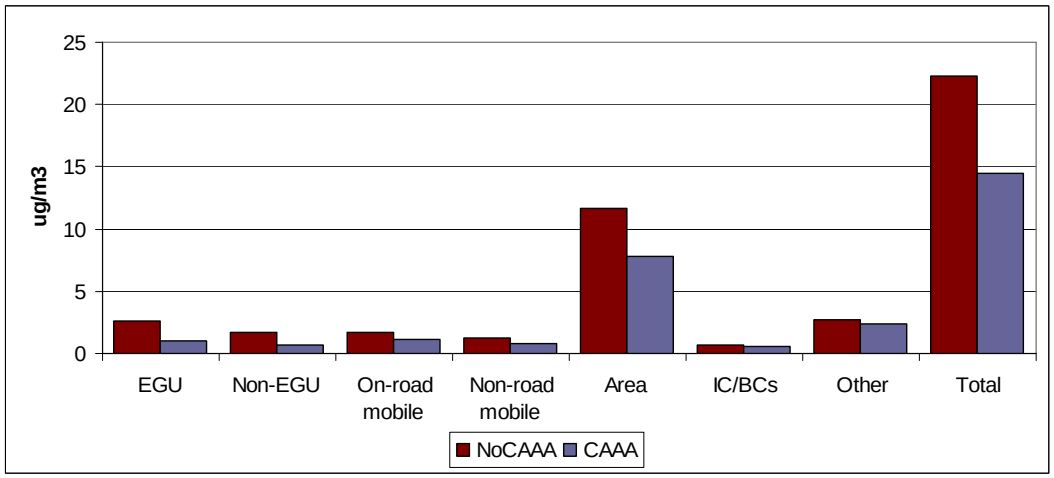
The effects of the CAAA measures on the simulated contributions also vary by location throughout the modeling domain. Figure IV-20 presents the PPTM results for both scenarios and each tagged source category for 34 locations throughout the modeling domain. These were selected to represent $PM_{2.5}$ monitoring sites for the subregions of the modeling domain defined by the EPA regions and are the same sites listed in Table IV-1.

**Figure IV-20. CMAQ/PPTM Source Category Contributions to Annual Average PM2.5 for the 2010 Scenarios.**

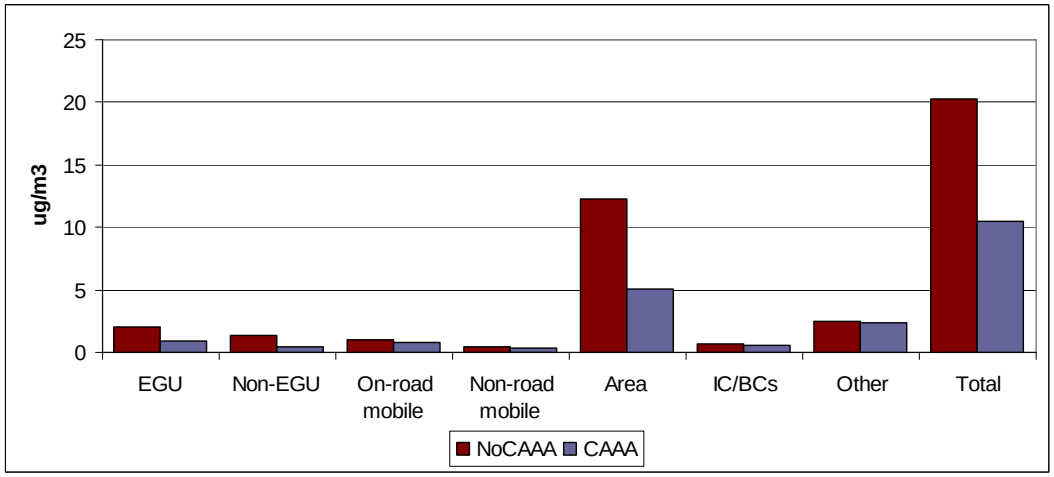
*(a) New Haven, CT*



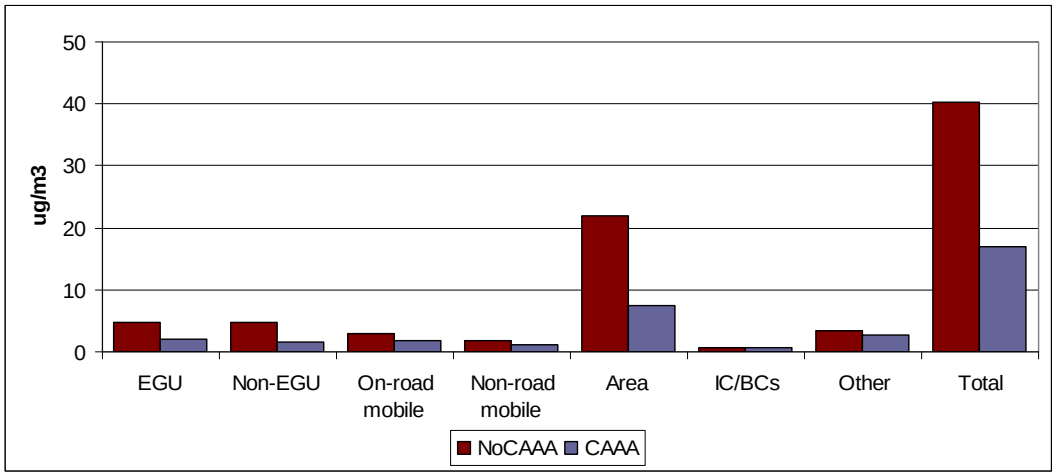

*(b) Boston, MA*



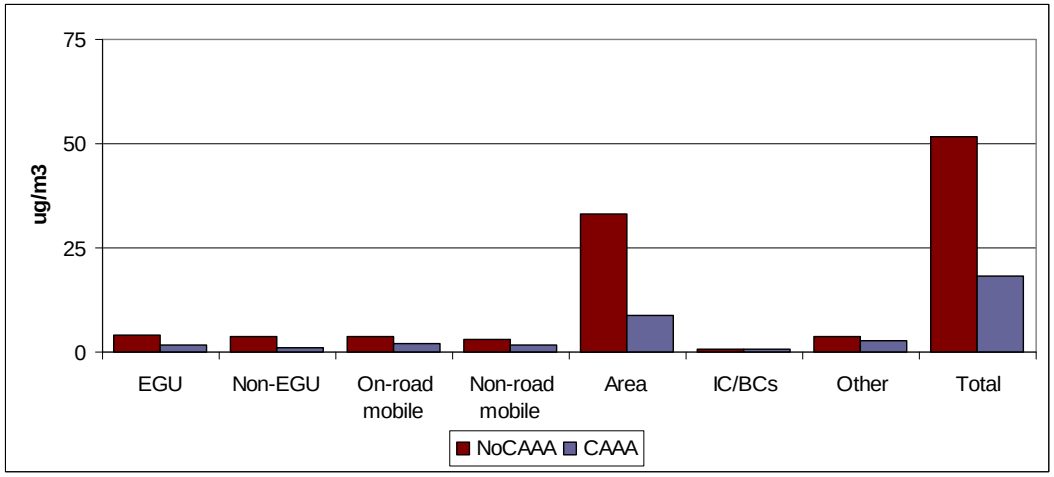

*(c) Portsmouth, NH*



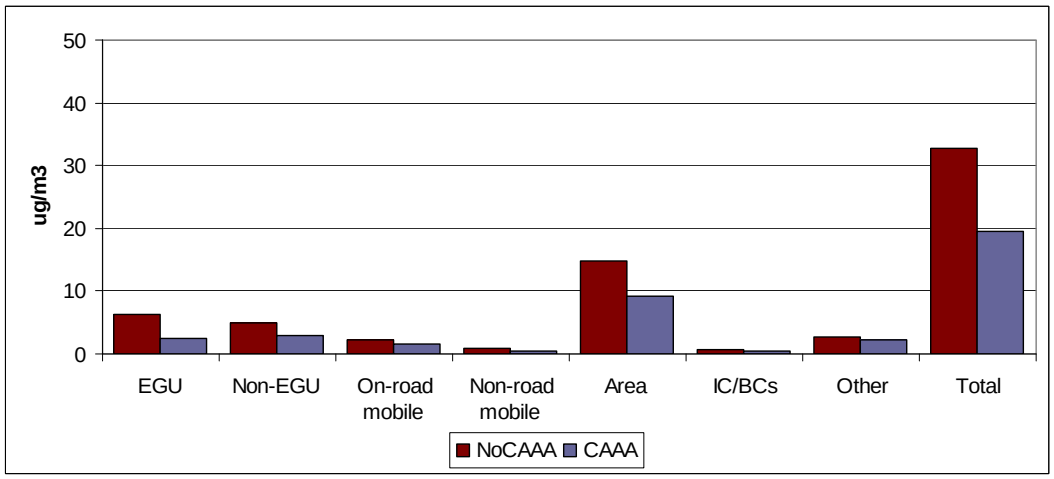
*(d) New Brunswick, NJ*



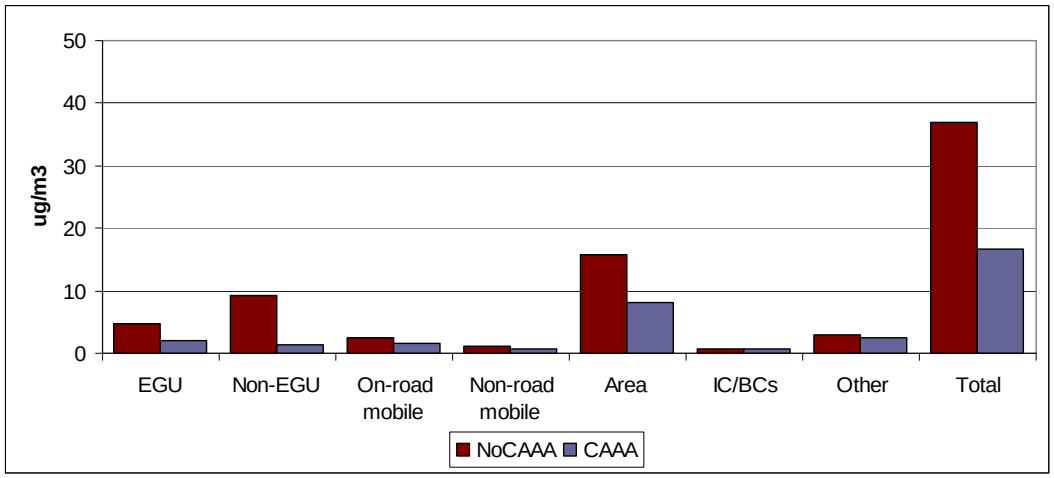

*(e) Bronx, NY (New York City)*



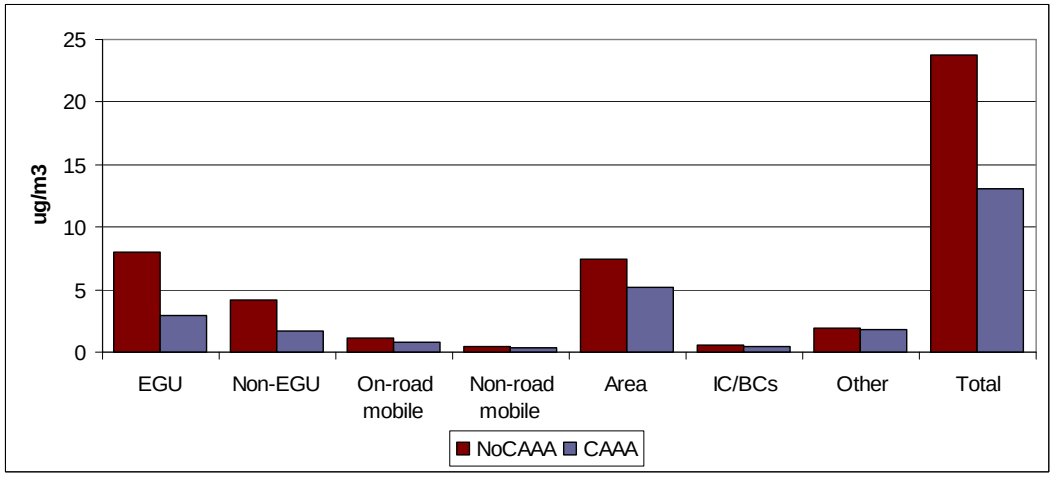

*(f) Fort Meade, MD (Baltimore)*



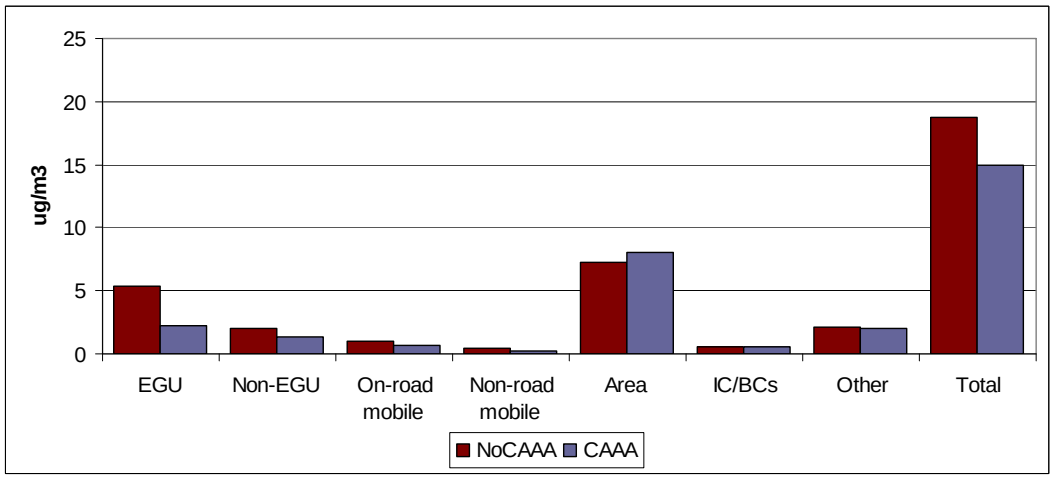
*(g) Philadelphia, PA*



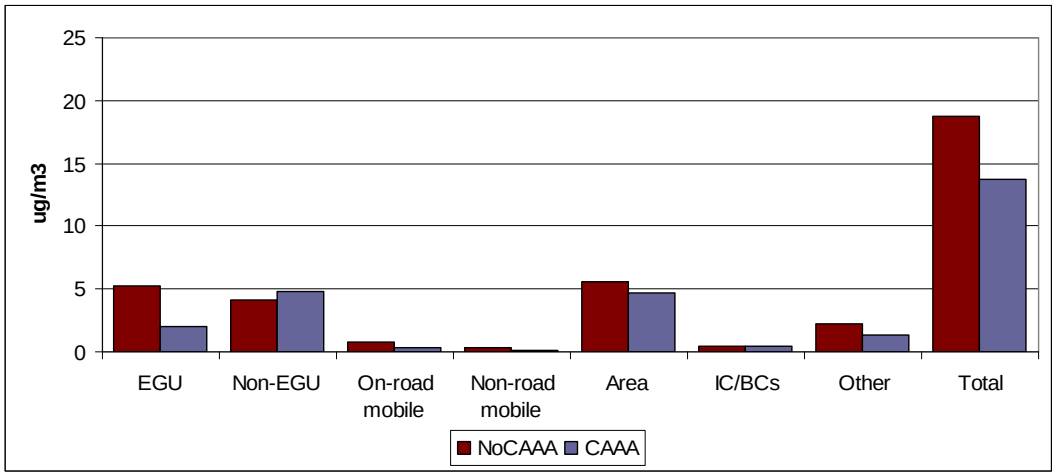

*(h) Pittsburgh, PA*



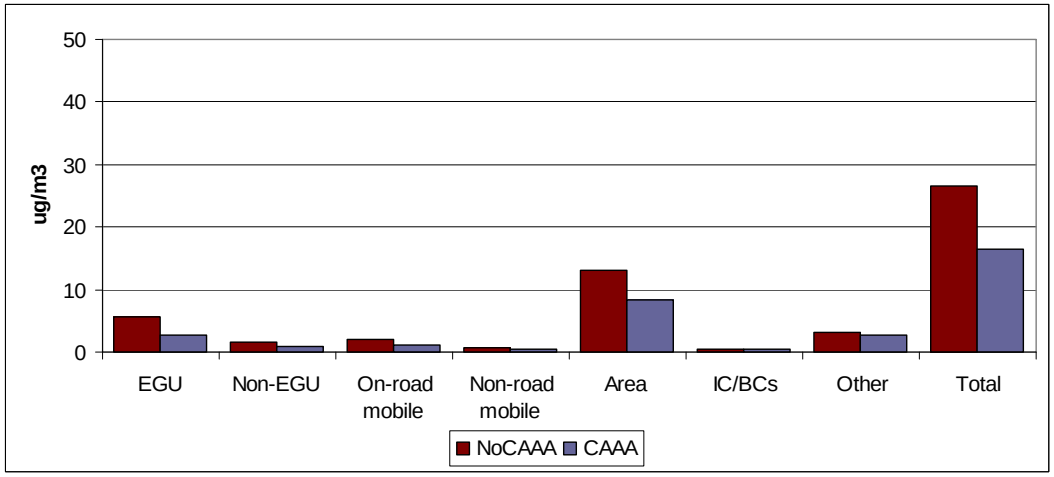

*(i) Richmond, VA*



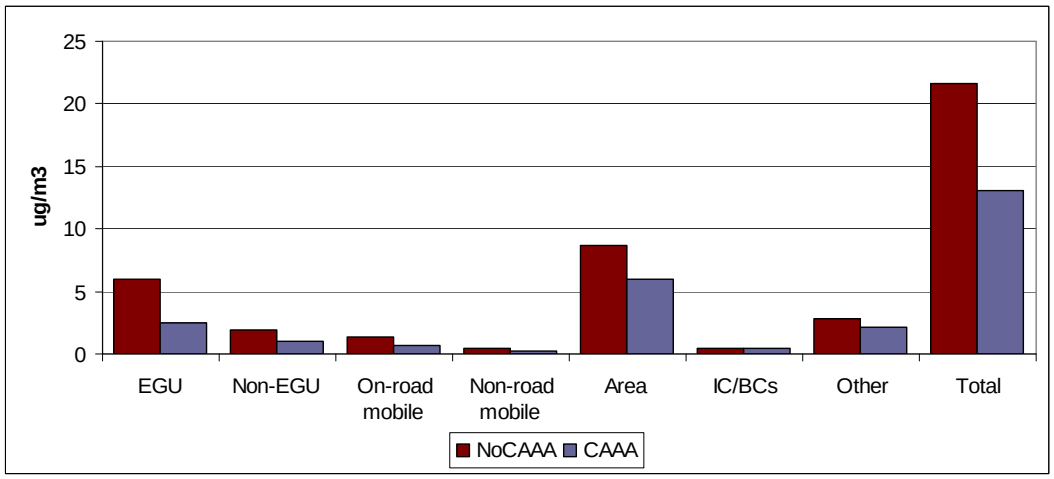
*(j) Pensacola, FL*



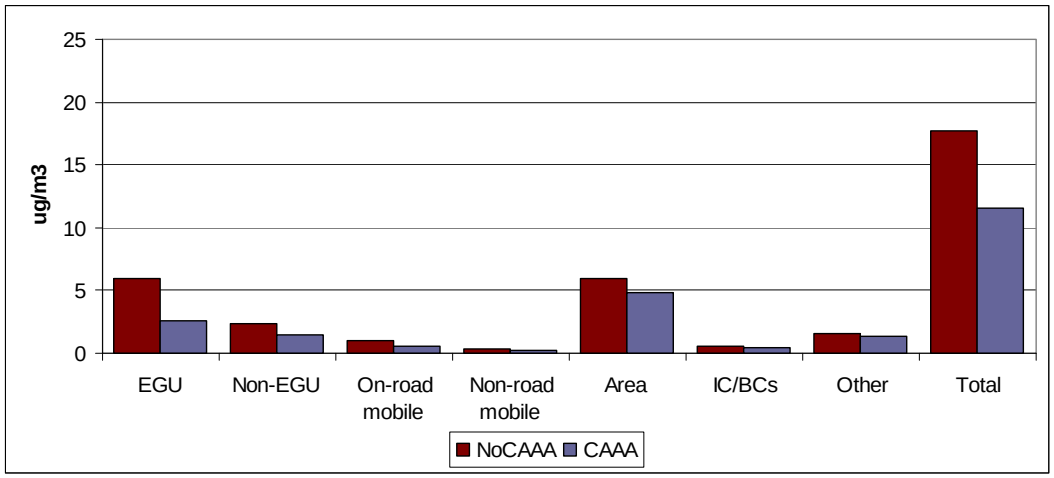

*(k) Atlanta, GA*



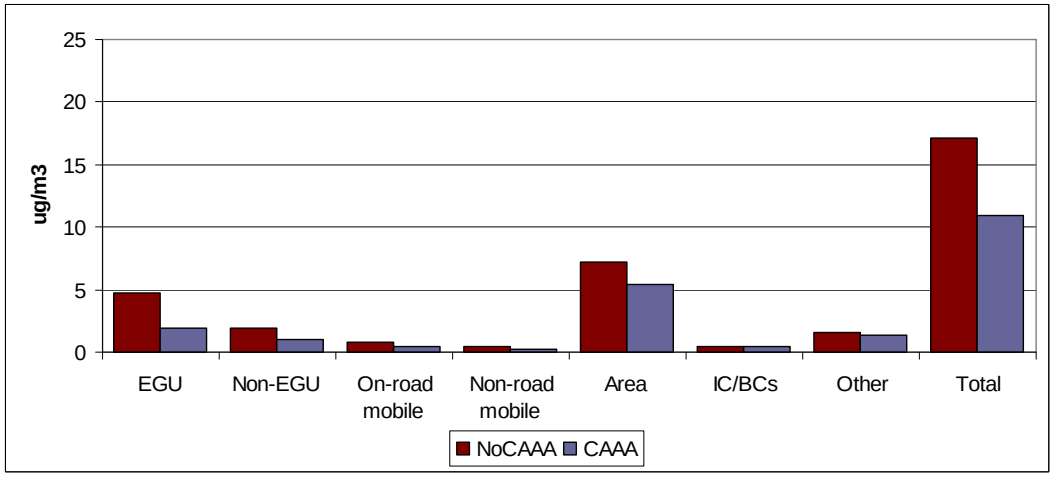

*(l) Charlotte, NC*



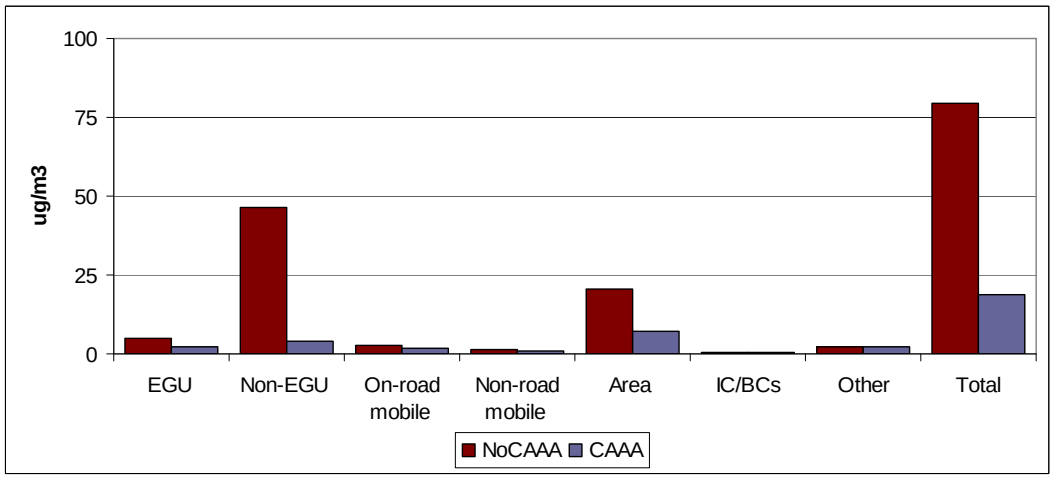
*(m) Knoxville, TN*



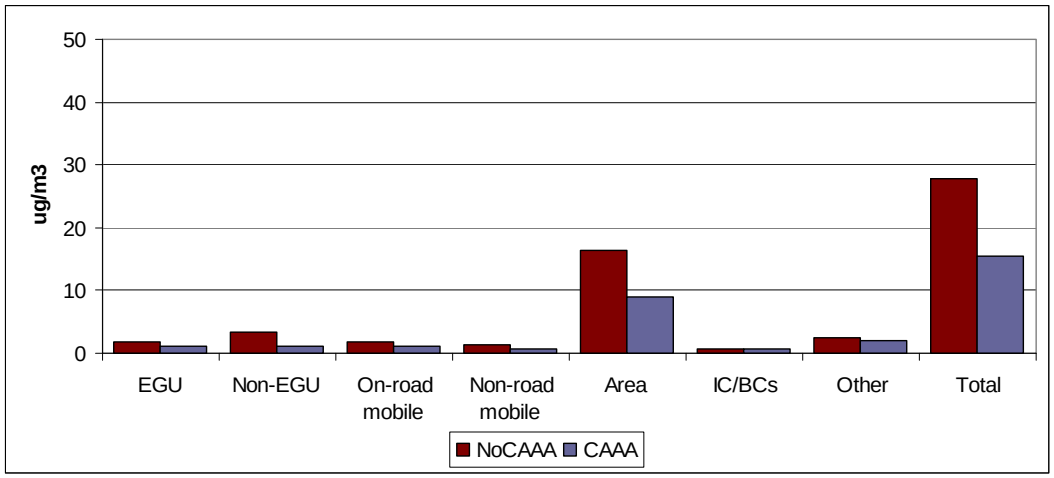

*(n) Memphis, TN*



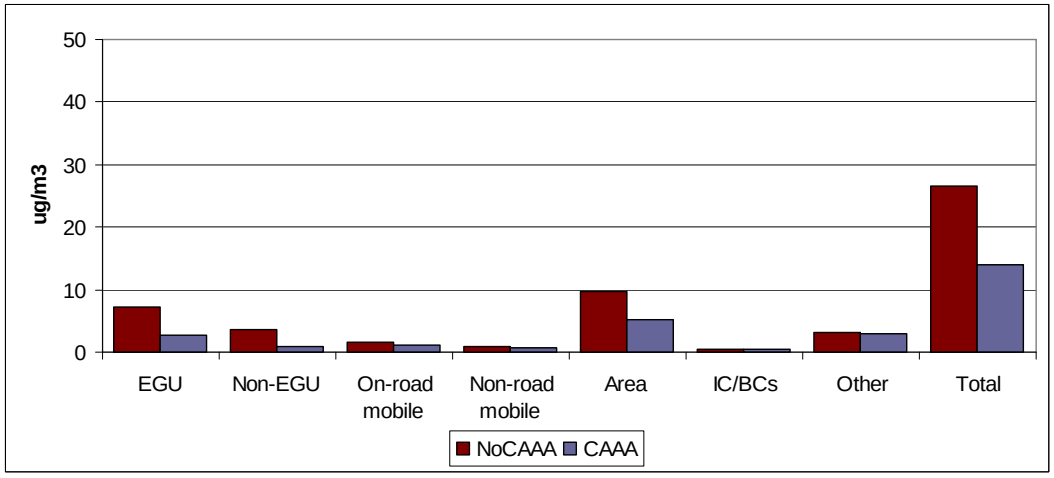

*(o) Chicago, IL*



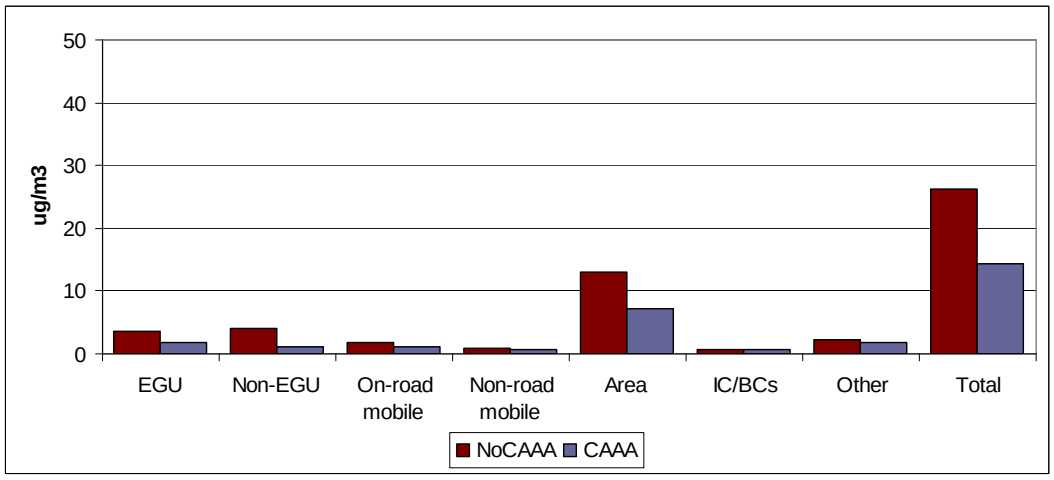
*(p) Minneapolis, MN*



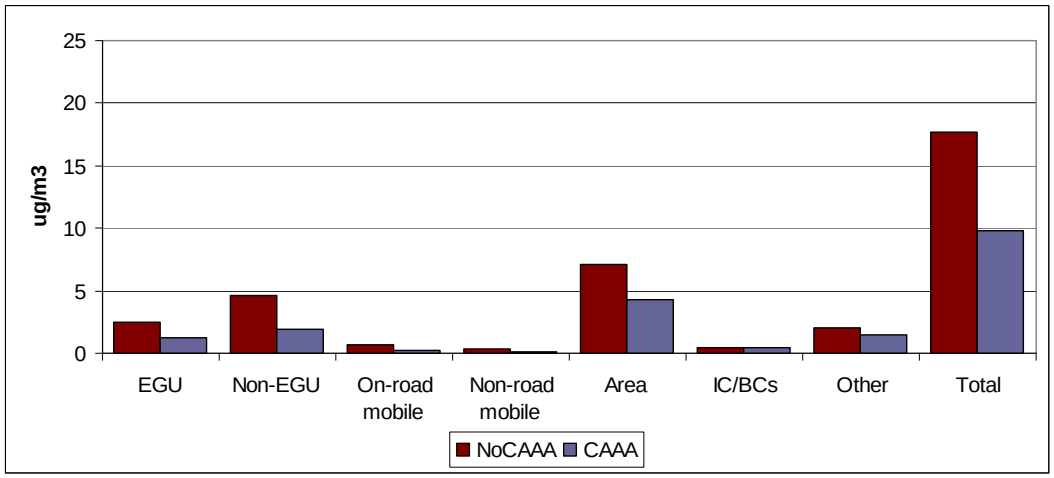

*(q) Cleveland, OH*



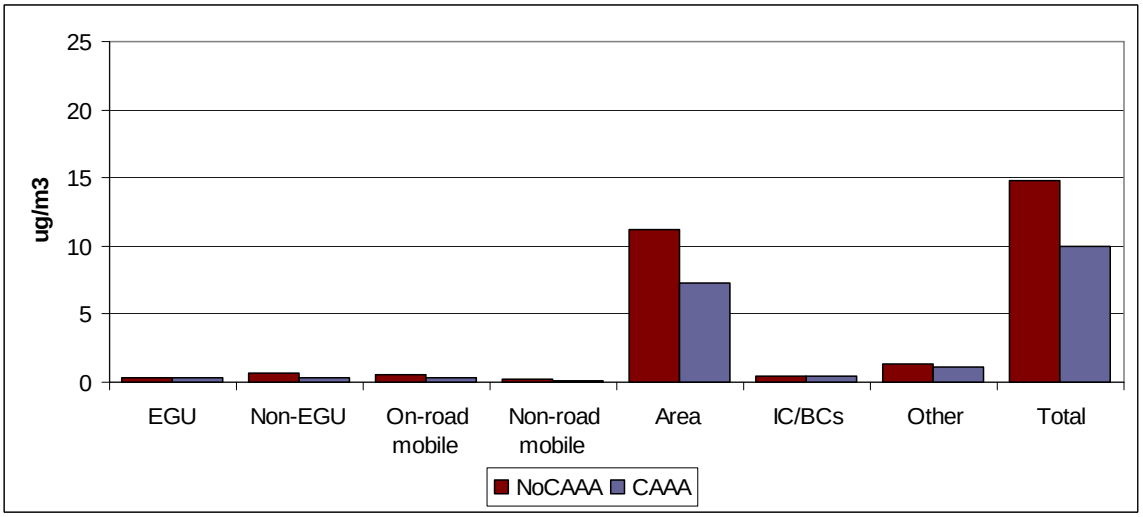

*(r) Milwaukee, WI*



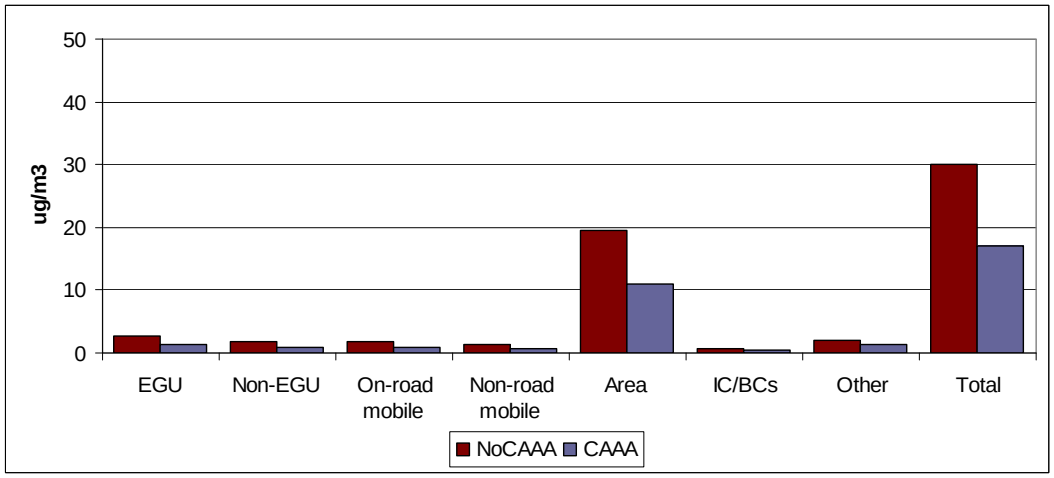
*(s) Baton Rouge, LA*



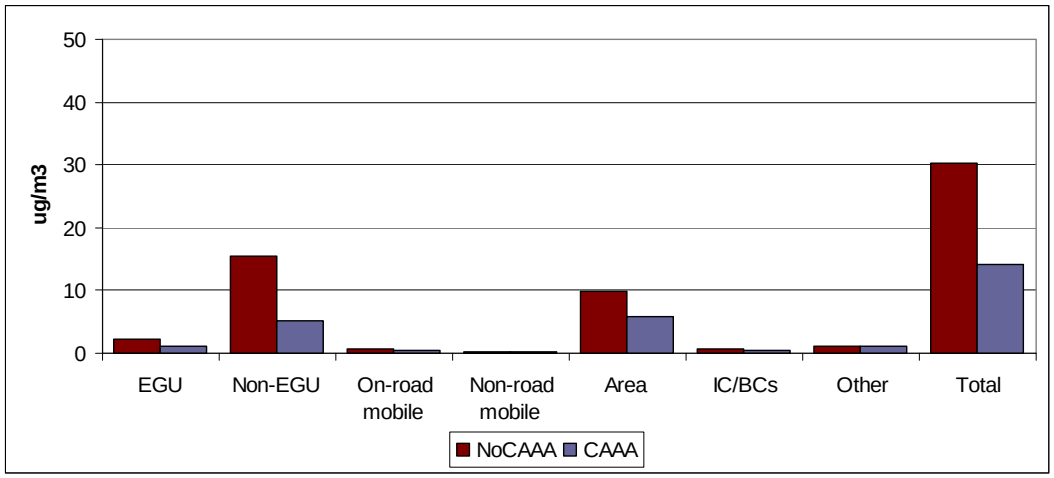

*(t) Albuquerque*



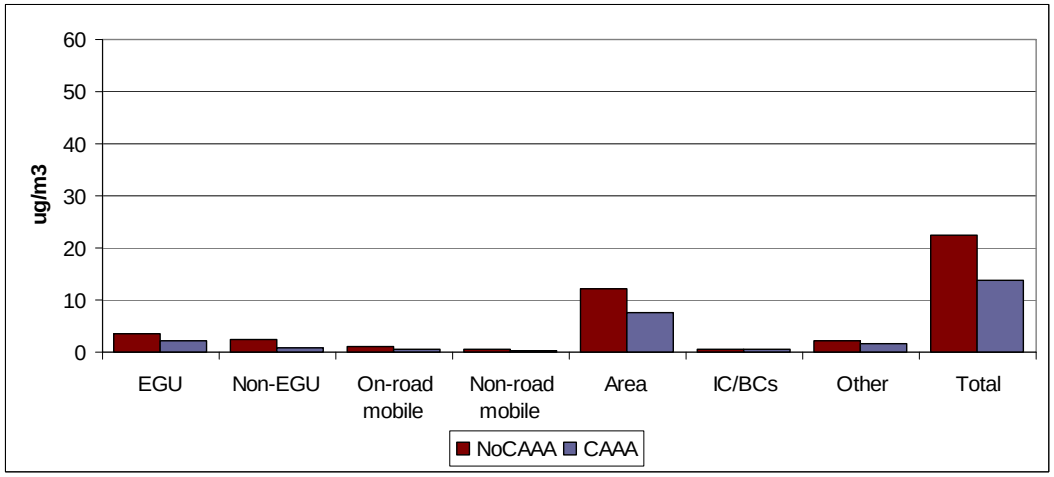

*(u) Dallas, TX*



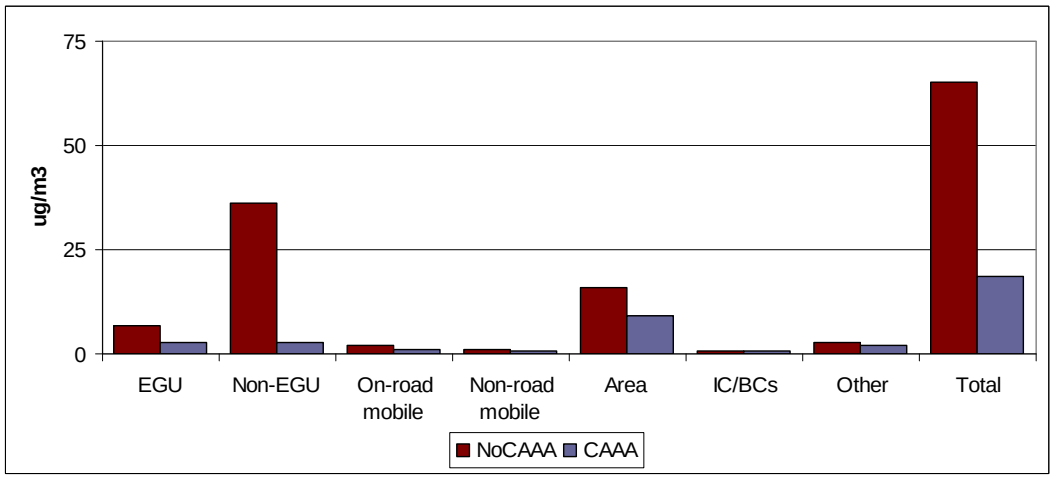
*(v) Houston, TX*



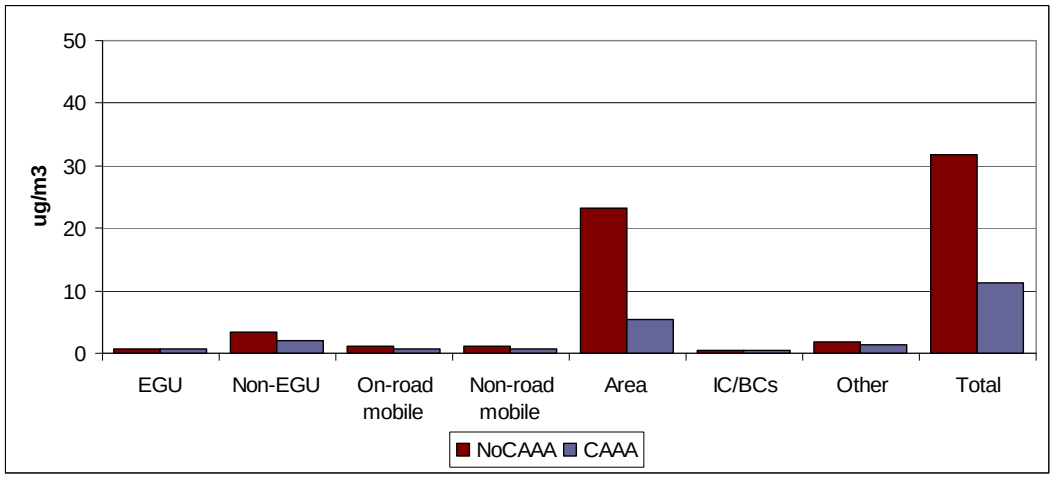

*(w) Kansas City, KS*



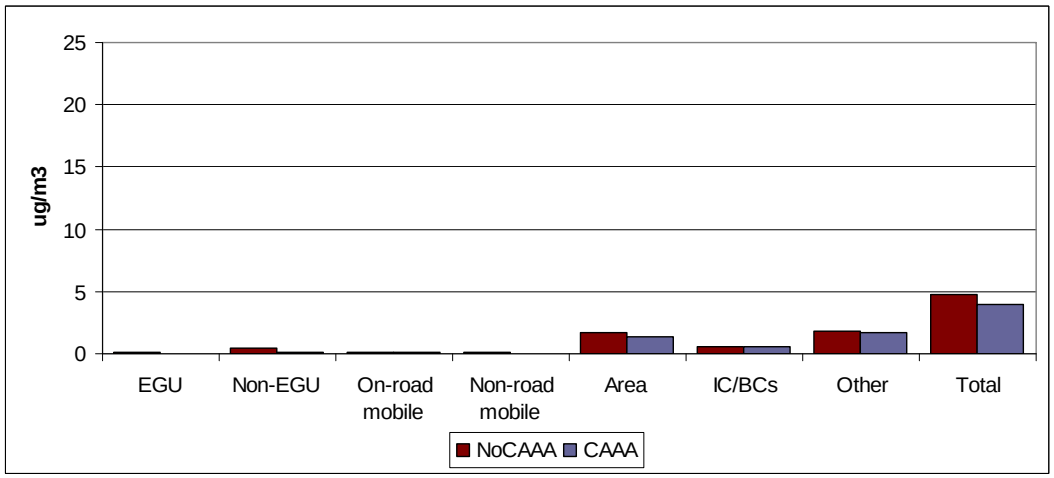

*(x) St. Louis, MO*



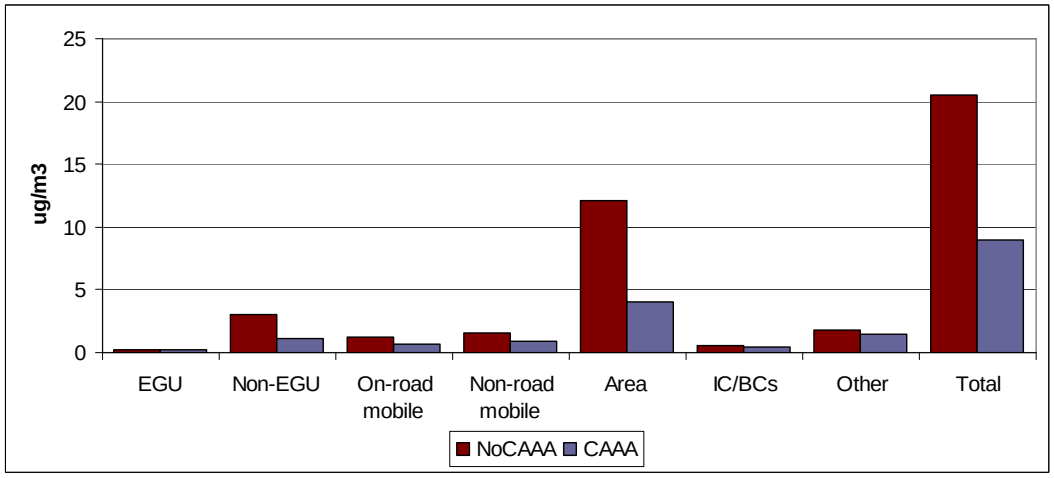
*(y) Denver, CO*



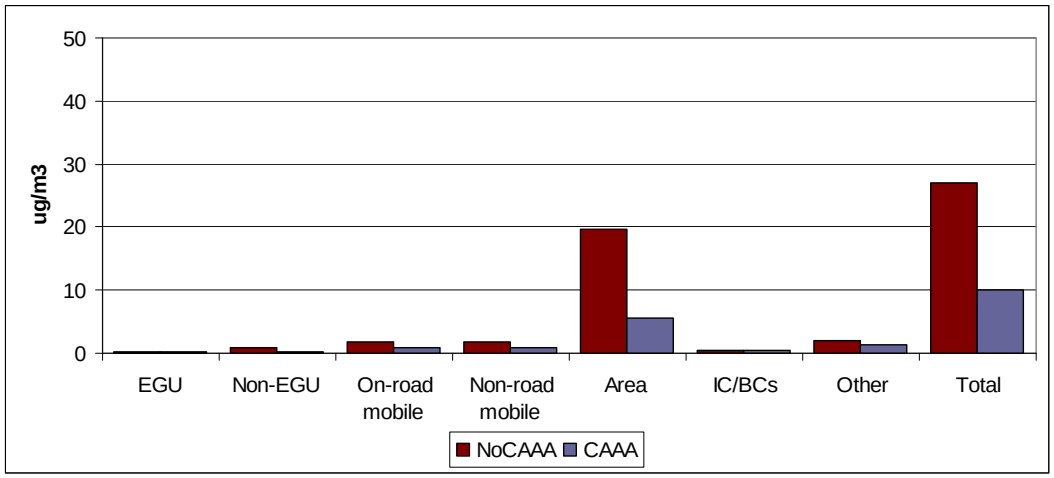

*(z) Missoula, MT*



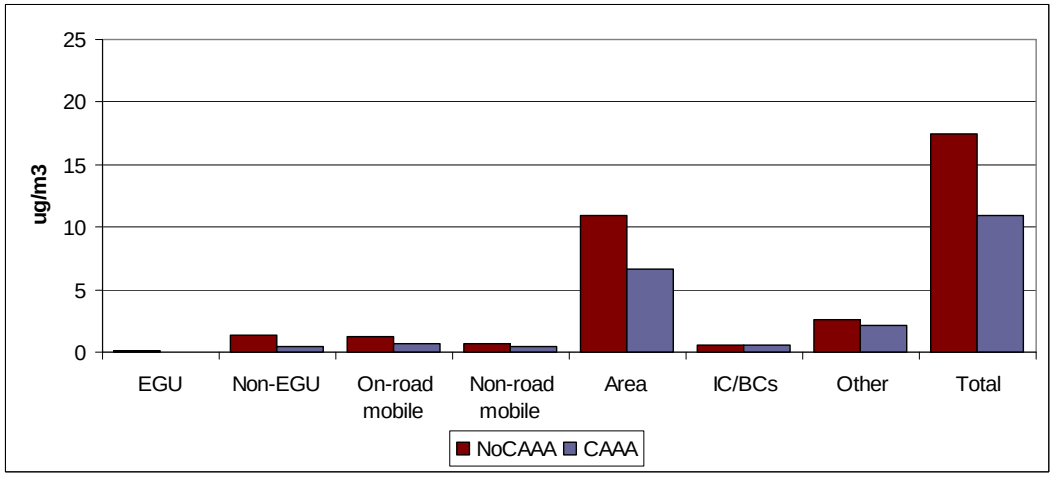

*(aa) Salt Lake City, UT*



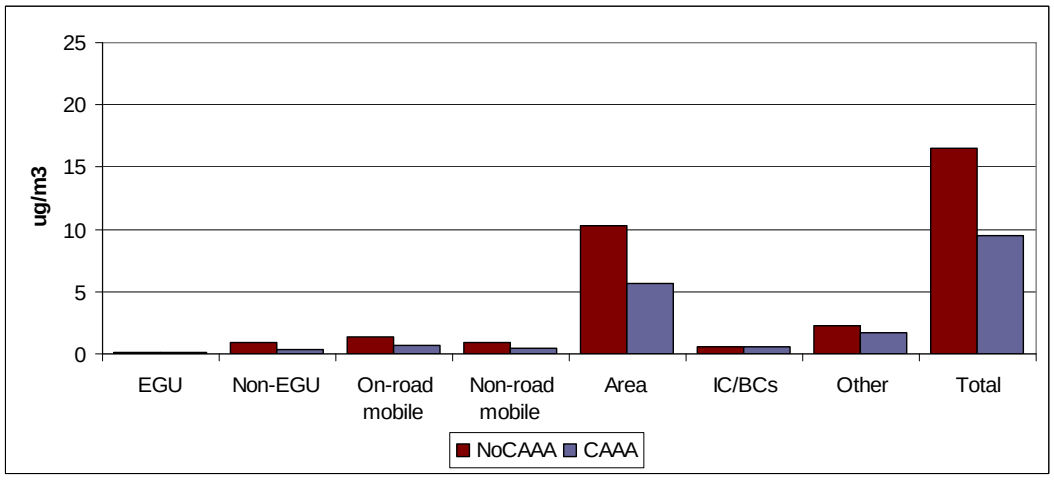
*(ab) Phoenix, AZ*



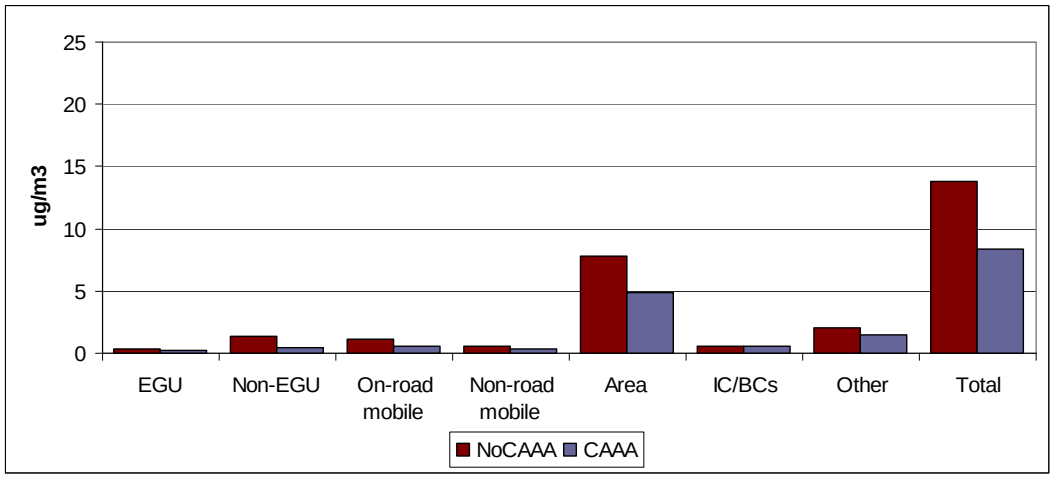

*(ac) Sacramento, CA*



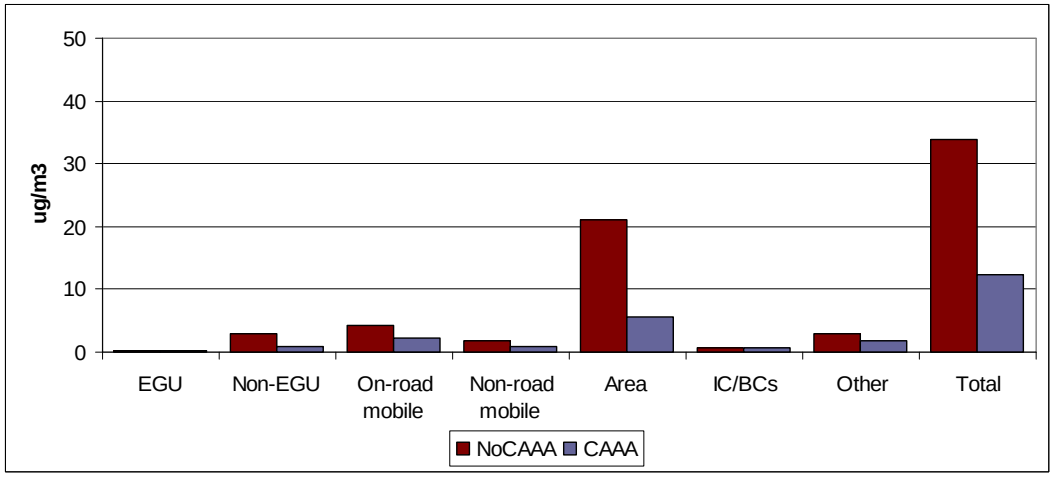

*(ad) Fresno, CA*



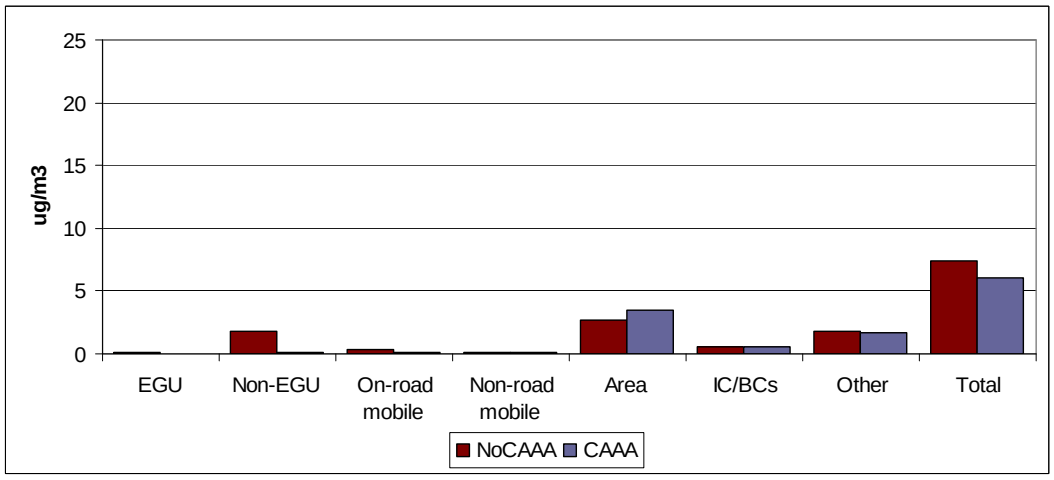
*(ae) Bakersfield, CA*



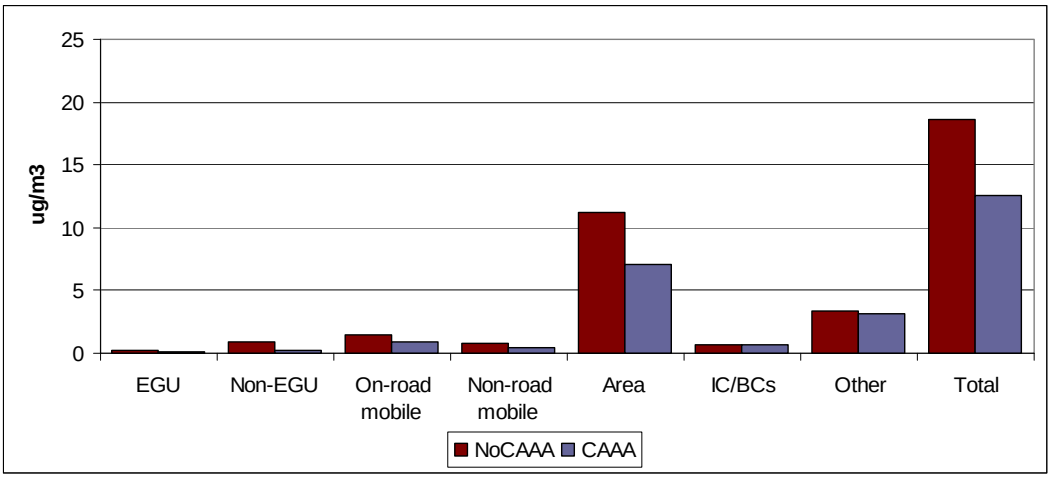

*(af) Los Angeles, CA*




*(ag) Boise, ID*



*(ah) Seattle, WA*




For all of the sites, the overall (total) simulated $PM_{2.5}$ concentration is lower under the CAAA scenario. The source category contributions to this reduction differ among the sites. For most sites, a reduction in the contribution from area (non-point, non-mobile) source emissions is a substantial part of the overall reduction. However, for some of the smaller urban areas such as Richmond (Figure IV-20i) and Boise (Figure IV-20ag), the contribution from these sources is greater with the CAAA. For many of the selected sites, reductions in the contributions from EGU and non-EGU point sources are important to the overall reduction. The plots reveal that, among the selected sites, a reduction in the contribution from EGU sources is an important component of the overall reduction in $PM_{2.5}$ concentrations for Pittsburgh (Figure IV-20h), Pensacola (Figure IV-20j), Charlotte (Figure IV-20l), Knoxville (Figure IV-20m), Memphis (Figure IV-20n), and Cleveland (Figure IV-20q). A reduction in the contribution from non-EGU sources is an important component of the overall reduction in $PM_{2.5}$ concentrations for Chicago (Figure IV-20o), Baton Rouge (Figure IV-20s), Houston (Figure IV-20v), and St. Louis (Figure IV-20x). For all sites, the contribution from on-road mobile, non-road, and all other sources is lower under the CAAA scenario.

## Ozone Modeling Results for the Eastern U.S.

This section of the report provides an overview of the CMAQ modeling results for the 12-km eastern U.S. (EUS) modeling domain. These modeling results were generated for the assessment of ozone related health effects. Recall that the simulation period for the EUS domain is May through September.

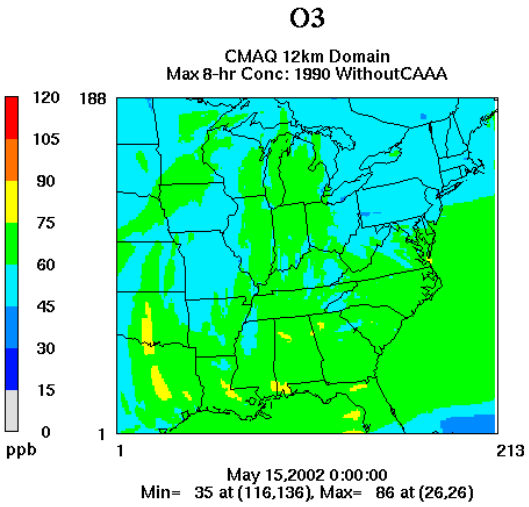
### 1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

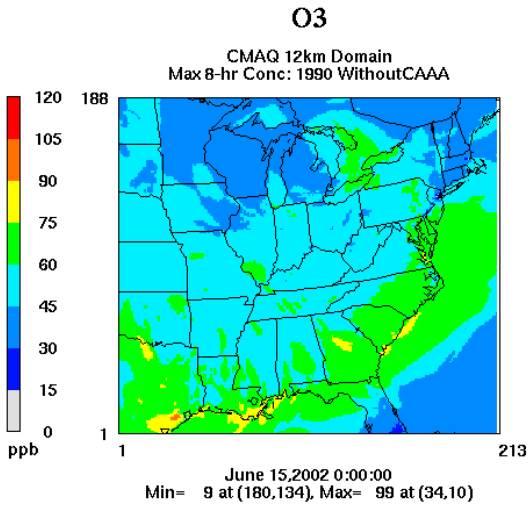
Figure IV-21 displays simulated daily maximum 8-hour ozone concentration (ppb) for the EUS domain for the 15$^{th}$ of May, June, July, August & September. The middle days of each month are used here to illustrate the month-to-month changes in ozone concentrations as well as a range of ozone concentration patterns.

**Figure IV-21. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for the 15th of May, June, July, August & September: 1990 Baseline Simulation.**

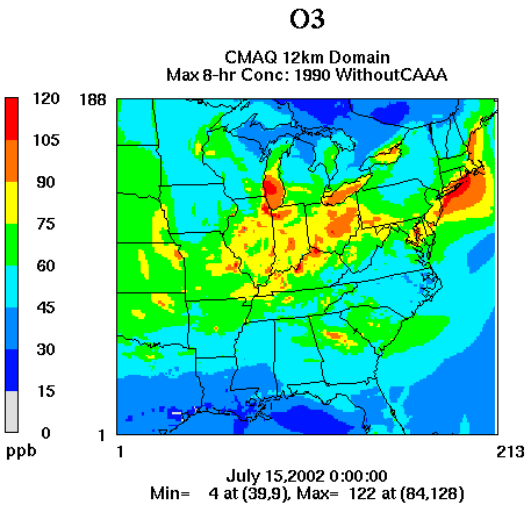
*(a) May*



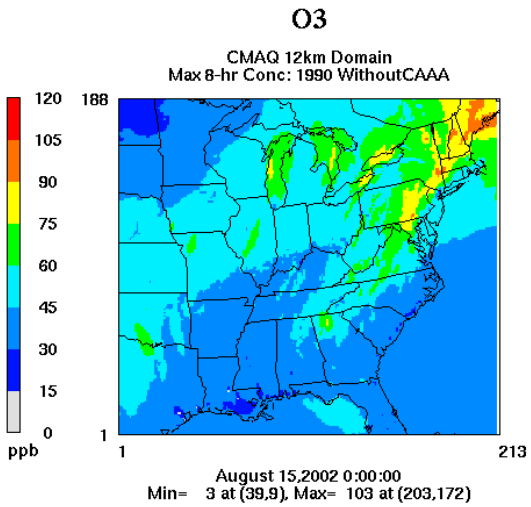

*(b) June*



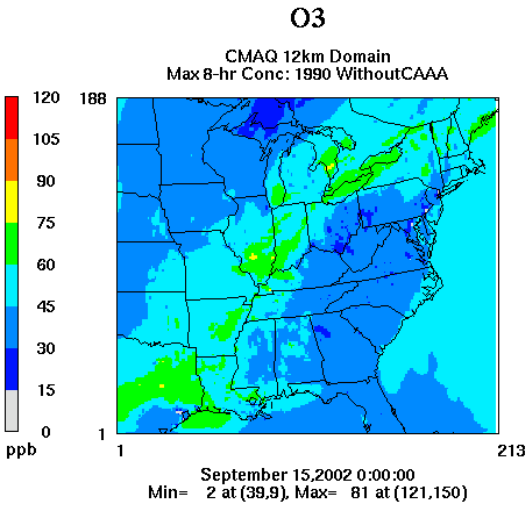

*(c) July*




*(d) August*



*(e) September*




Ozone gradually builds up in the South during the early part of the ozone season, while numerous areas of the South, Midwest, and Northeast are affected during the peak summer months. For this subset of days, July 15th has the most widespread high ozone as well as the highest overall concentrations.

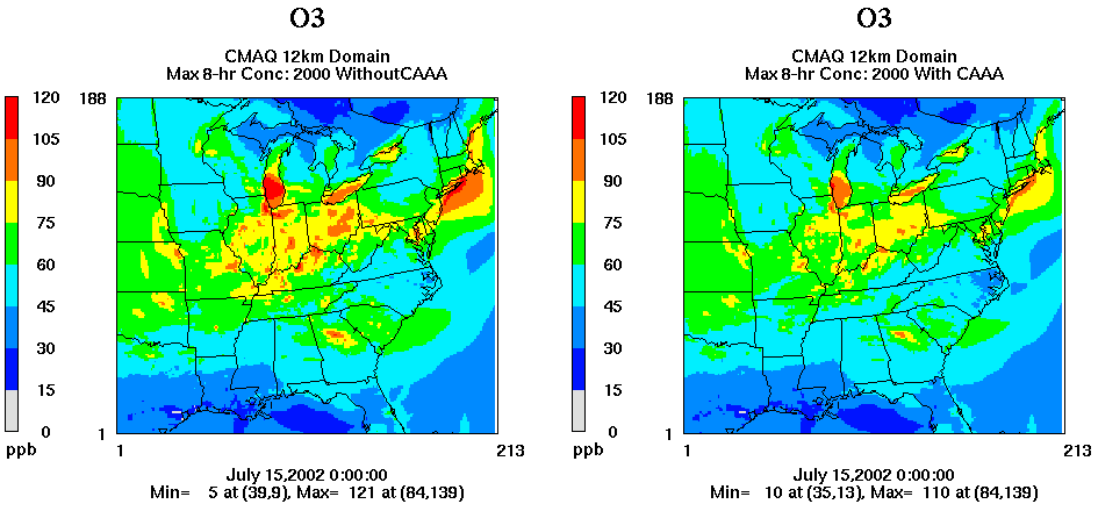
## Without-CAAA2000 and with-CAAA2000 Scenarios

In this analysis, 2000 is the initial year for comparison of the without- and with-CAAA scenarios. The without-CAAA emissions for this year were projected from the 1990 base-year emissions. The with-CAAA emissions were based on emission inventory data for 2000. The emissions are summarized and compared in Section 2.

Figure IV-22 displays simulated daily maximum 8-hour ozone concentration (ppb) for the EUS domain for the 2000 without-CAAA (Figure IV-22a) and 2000 with-CAAA (Figure IV-22b) scenarios. The results for July 15th are shown. This day was selected as a representative ozone-season day for comparison of the without- and with-CAAA scenarios.

**Figure IV-22. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2000 Scenarios.**

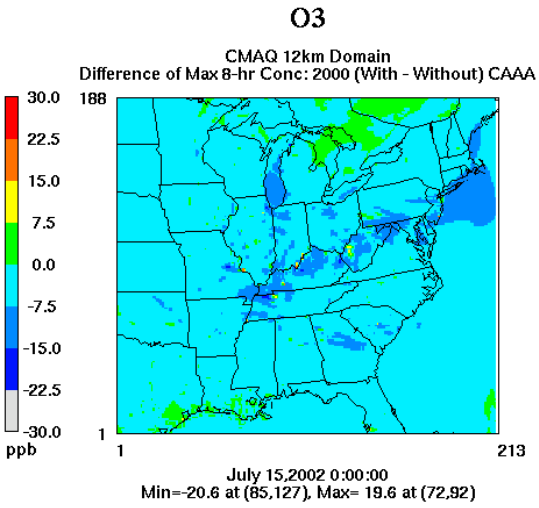
*(a) Without CAAA* *(b) With CAAA*




The results for the 12-km EUS domain for ozone for 15 July are very similar to those for the 36-km CONUS domain. For the year 2000 scenarios, high simulated ozone occurs downwind and in the vicinity of large metropolitan areas (Atlanta, Chicago, Cincinnati, New York, etc.). For the 2000 with-CAAA scenario, simulated ozone concentrations are reduced in these areas.

Figure IV-23 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-23. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.**



As shown in the results for the 36-km domain for these scenarios, simulated ozone is reduced in areas of high concentrations in the Ohio Valley area, over Lake Michigan, offshore of New Jersey/New York, and in the Atlanta area, when emission reductions due to CAAA controls are included for the year 2000.

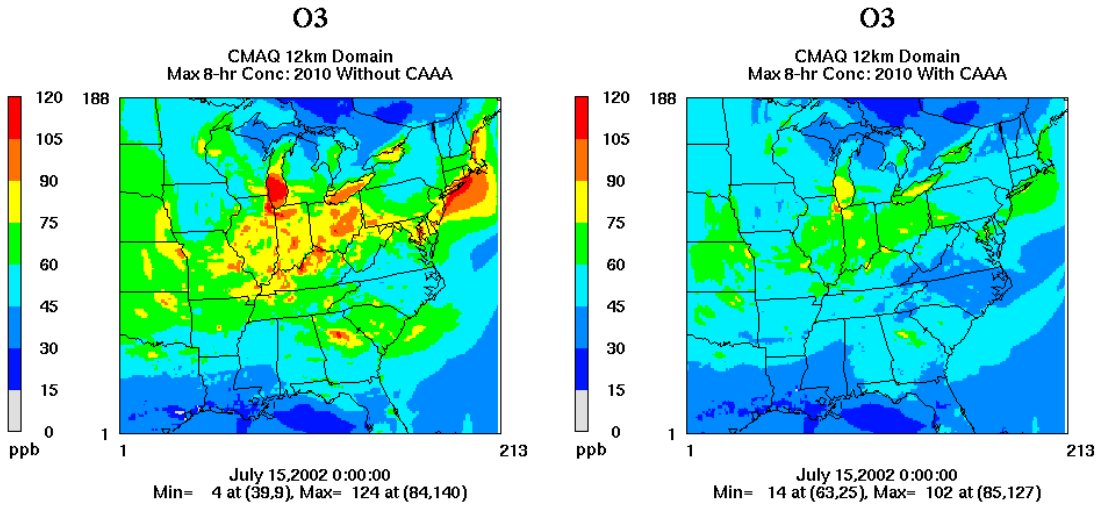
## Without-CAAA2010 and with-CAAA2010 Scenarios

The 2010 without-CAAA emissions were projected from the 1990 base-year emissions. The 2010 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the with- and without-CAAA scenarios are greater than for 2000.

Figure IV-24 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for July 15th for the 2010 without-CAAA (Figure IV-24a) and 2010 with-CAAA (Figure IV-24b) scenarios.

**Figure IV-24 Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2010 Scenarios.**

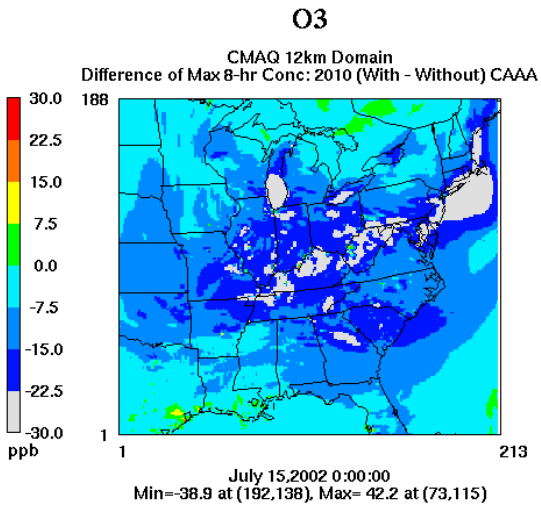
*(a) Without CAAA* *(b) With CAAA*




For the 2010 scenarios, simulated ozone is increased compared to the year 2000 values in the same areas for the without-CAAA scenario in which precursor emissions are grown without controls. The maximum simulated 8-hr ozone concentration for this day is 124 ppb, compared to 121 ppb for the year 2000 without-CAAA scenario. Simulated ozone is substantially lower in the with-CAAA scenario.

Figure IV-25 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-25. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.**




The difference plot comparing the 2010 scenarios shows wide areas of simulated ozone reductions throughout the EUS domain, with a maximum decrease in simulated 8-hour maximum concentration of nearly 40 ppb, when CAAA controls are included.

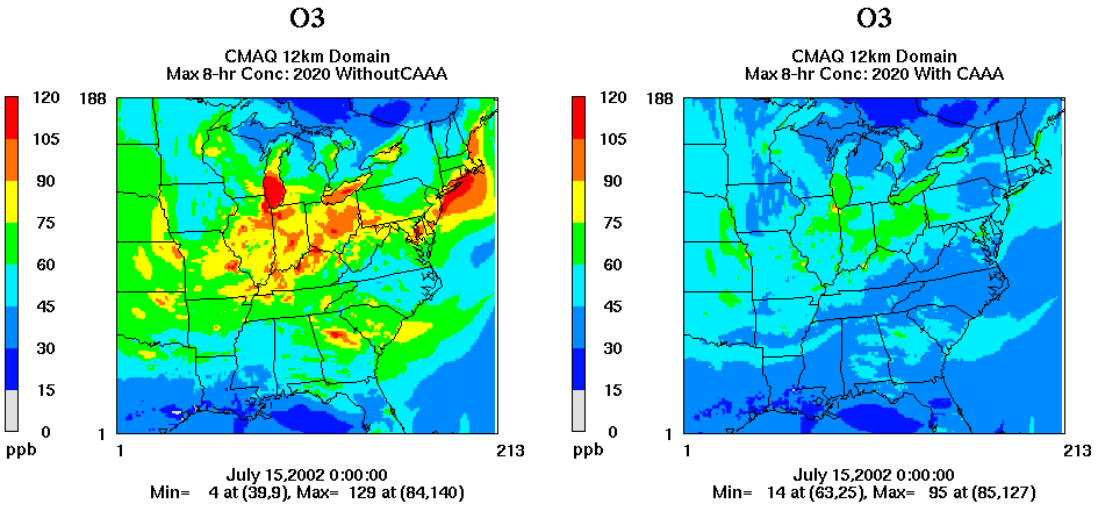
## Without-CAAA2020 and with-CAAA2020 Scenarios

The 2020 without-CAAA emissions were projected from the 1990 base-year emissions. The 2020 with-CAAA emissions were projected from the 2000 base-year emissions. The emissions are summarized and compared in Section 2. The differences in emissions and simulated concentrations between the 2020 with- and without-CAAA scenarios are greater than for the other Section 812 scenario pairs.

Figure IV-26 displays simulated daily maximum 8-hour ozone concentration (ppb) for the CONUS domain for the 15$^{th}$ of July for the 2020 without-CAAA (Figure IV-26a) and 2020 with-CAAA (Figure IV-26b) scenarios.

**Figure IV-26. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2020 Scenarios.**

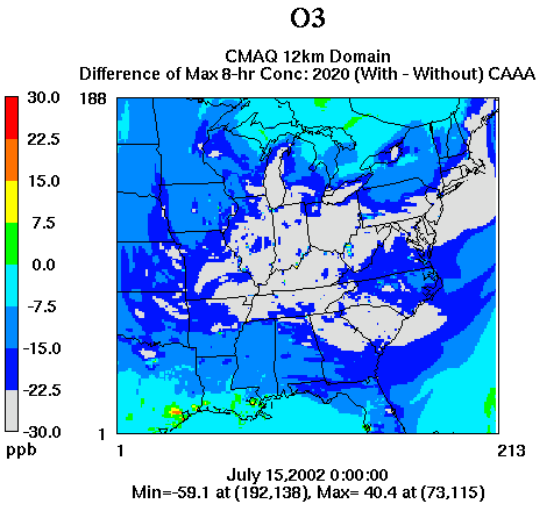
*(a) Without CAAA* *(b) With CAAA*




For the 2020 without CAAA scenario, simulated ozone concentrations increase beyond 2010 levels due to expected further increases in precursor emissions from growth during this period. In the absence of emission controls, the peak simulated concentration in the EUS domain for this day is 129 ppb, compared to 124 ppb for the 2010 without-CAAA scenario. When controls for 2020 are included, the maximum simulated 8-hr ozone concentration for this day is 95 ppb.

Figure IV-27 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-27. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the EUS Domain for 15 July: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.**



For 2020, the inclusion of CAAA controls and the resulting reduction in precursor emissions shows major reductions in simulated ozone in very large portions of the EUS domain. The gray area in the figure denotes an area with simulated 8-hr ozone reductions of greater than 22.5 ppb, with a maximum reduction of nearly 60 ppb in the New Jersey area.

## Summary of the Effects of the CAAA on Ozone Quality

Tabular summaries of the 12-km CMAQ modeling results for selected subregions and monitoring sites are presented in this section. Again, for the 12-km domain and five-month simulation period, the focus is on ozone.

The subregions follow the EPA region definitions. The EPA region definitions for all regions were provided earlier in this section. Only Regions 1 through 7 are partly or fully contained within the EUS domain and the definitions used for this analysis are as follows:

- **Region 1:** Connecticut, Maine (partial), Massachusetts, New Hampshire, Rhode Island, Vermont
- **Region 2:** New Jersey, New York
- **Region 3:** Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia
- **Region 4:** Alabama, Florida (partial), Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
- **Region 5:** Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
- **Region 6:** Arkansas, Louisiana, Oklahoma (partial), Texas (partial)
- **Region 7:** Iowa (partial), Kansas (partial), Missouri (partial), Nebraska (partial)

Ozone monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. In some cases, these differ from the $PM_{2.5}$ monitoring sites but were selected to represent approximately the same areas. The EUS ozone monitoring sites are listed in Table IV-5.

**Table IV-5. Ozone Monitoring Sites Used in the Analysis of CMAQ Results for the EUS Modeling Domain for the 812 Modeling Study.**

| Region | Site Location |
|---|---|
| **Region 1** | Groton, CT |
| | Truro, MA |
| | Bar Harbor, ME |
| | Portsmouth, NH |
| **Region 2** | East Brunswick, NJ |
| | Putnam Co., NY (New York City) |
| **Region 3** | Davidsonville, MD (Baltimore) |
| | Bristol, PA (Philadelphia) |
| | Pittsburgh, PA |
| | Richmond, VA |
| **Region 4** | Pensacola, FL |
| | Atlanta, GA |
| | Charlotte, NC |
| | Knoxville, TN |

| Region | Site Location |
|---|---|
| **Region 5** | Chicago, IL |
| | Stillwater, MN (Minneapolis) |
| | Cleveland, OH |
| | Sheboygan, WI |
| **Region 6** | Marion, AR (Memphis) |
| | Baton Rouge, LA |
| | Frisco, TX (Dallas) |
| | Houston, TX |
| **Region 7** | Kansas City, KS |
| | St Louis, MO |

Several metrics are used to summarize the modeling results for ozone including peak simulated 8-hour ozone concentration, ozone exceedance exposure for a threshold of 75 ppb, and estimated design value. These metrics were defined previously in this report.

Table IV-6 lists the ozone exceedance exposure for each subregion and scenario. This metric is the amount by which the simulated ozone concentration exceeds 75 ppb, summed over all grid cells (within the selected area) and all days.

**Table IV-6. Ozone Exceedance Exposure Based on 75 ppb for the EUS Domain and all Section 812 Scenarios. Units are ppb * grid cell * days.**

| Region | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| Region 1 | 489,338 | 388,979 | 143,159 | 460,610 | 5,956 | 633,378 | 541 |
| Region 2 | 643,653 | 563,680 | 204,738 | 695,386 | 15,870 | 929,021 | 831 |
| Region 3 | 1,521,879 | 1,471,197 | 454,546 | 1,899,539 | 24,129 | 2,659,081 | 3,389 |
| Region 4 | 2,789,957 | 3,686,211 | 1,283,666 | 5,043,904 | 95,090 | 7,542,997 | 7,133 |
| Region 5 | 3,030,564 | 3,225,655 | 1,093,113 | 3,936,466 | 89,895 | 5,347,470 | 24,168 |
| Region 6 | 798,243 | 936,108 | 265,873 | 1,319,936 | 25,620 | 2,298,802 | 4,099 |
| Region 7 | 441,020 | 516,665 | 147,570 | 671,918 | 16,940 | 1,037,752 | 3,263 |

For the without-CAAA scenarios, a mix of increases and decreases between 1990 and 2000 (depending on the region) is followed by a steady increase with time. The largest increases tend to occur between 2010 and 2020. Ozone exceedance exposure consistently decreases with time for the with-CAAA scenarios. For all regions, the greatest decrease occurs between 1990 and 2000. By 2020, the reduction is nearly 100 percent for most regions – indicating that only a small fraction of grid cells and days have simulated ozone concentrations greater than 75 ppb.

Table IV-7 lists the peak simulated 8-hour ozone concentration for each EUS monitoring site and scenario.

**Table IV-7. Simulated Maximum 8-Hour Ozone Concentration (ppb) for Selected Monitoring Sites in the EUS Domain and all Section 812 Scenarios.**

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| **Region 1 Sites** | | | | | | | |
| Groton, CT | 118.0 | 113.0 | 100.6 | 113.5 | 76.0 | 118.0 | 63.0 |
| Truro, MA | 123.0 | 122.0 | 115.2 | 125.7 | 96.1 | 134.0 | 81.0 |
| Bar Harbor, ME | 113.0 | 108.0 | 97.5 | 109.5 | 81.1 | 114.0 | 69.7 |
| Nashua, NH | 92.3 | 90.0 | 81.5 | 91.6 | 70.7 | 94.4 | 64.7 |
| **Region 2 Sites** | | | | | | | |
| East Brunswick, NJ | 106.0 | 106.0 | 93.7 | 108.1 | 81.3 | 111.0 | 66.7 |
| Putnam Co., NY (New York City) | 117.0 | 113.0 | 102.4 | 115.8 | 81.4 | 121.0 | 68.1 |
| **Region 3 Sites** | | | | | | | |
| Davidsonville, MD | 118.0 | 114.0 | 105.0 | 117.5 | 83.9 | 123.0 | 70.9 |
| Bristol, PA (Philadelphia) | 119.0 | 118.0 | 107.6 | 120.7 | 87.7 | 124.0 | 74.0 |
| Pittsburgh, PA | 111.0 | 110.0 | 97.4 | 111.9 | 86.7 | 115.0 | 82.6 |
| Richmond, VA | 98.4 | 100.0 | 91.8 | 103.4 | 80.0 | 108.0 | 74.9 |
| **Region 4 Sites** | | | | | | | |
| Pensacola, FL | 109.0 | 106.0 | 95.9 | 107.5 | 86.3 | 110.0 | 79.7 |
| Atlanta, GA | 137.0 | 133.0 | 128.9 | 136.8 | 118.9 | 140.0 | 93.1 |
| Charlotte, NC | 101.0 | 109.0 | 100.8 | 115.9 | 84.2 | 123.0 | 70.9 |
| Knoxville, TN | 114.0 | 113.0 | 104.4 | 115.7 | 75.8 | 119.0 | 63.5 |
| **Region 5 Sites** | | | | | | | |
| Chicago, IL | 129.0 | 120.0 | 104.4 | 123.5 | 102.0 | 129.0 | 102.8 |
| Stillwater, MN (Minneapolis) | 97.9 | 97.8 | 90.2 | 100.3 | 81.8 | 104.0 | 77.0 |
| Cleveland, OH | 108.0 | 107.0 | 99.3 | 109.3 | 82.7 | 113.0 | 72.6 |
| Sheboygan, WI | 143.0 | 140.0 | 126.9 | 142.9 | 109.0 | 149.0 | 97.7 |
| **Region 6 Sites** | | | | | | | |
| Marion, AR (Memphis) | 109.0 | 113.0 | 97.1 | 116.5 | 78.3 | 121.0 | 68.8 |
| Baton Rouge, LA | 87.7 | 87.5 | 81.2 | 88.8 | 76.8 | 92.6 | 71.9 |
| Frisco, TX (Dallas) | 95.0 | 94.9 | 86.8 | 96.7 | 77.7 | 100.0 | 71.4 |
| Houston, TX | 106.0 | 106.0 | 97.9 | 106.9 | 84.9 | 111.0 | 77.8 |
| **Region 7 Sites** | | | | | | | |
| Kansas City, KS | 97.6 | 97.4 | 90.3 | 99.9 | 82.6 | 104.0 | 75.9 |
| St. Louis, MO | 118.0 | 118.0 | 107.3 | 120.0 | 92.7 | 124.0 | 86.3 |

Simulated maximum 8-hour ozone concentrations generally increase with time for the without-CAAA scenarios, although there are some simulated decreases between 1990 and 2000. Conversely, the 8-hour ozone concentrations decrease with time for the with-CAAA scenarios (with one exception for Chicago between 2010 and 2020).

Table IV-8 presents the estimated future-year 8-hour ozone design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation-based) design value. Site-specific model-derived relative reduction factors were applied to the observation-based (baseline) design values in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 75 ppb is an indicator of future-year attainment.

**Table IV-8. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for Selected Monitoring Sites in the EUS Domain and the Future-Year Section 812 Scenarios.**

| | 2002 DV | 2010 w/o CAAA | 2010 w/CAAA | 2020 w/o CAAA | 2020 w/CAAA |
|---|---|---|---|---|---|
| **Region 1 Sites** | | | | | |
| Groton, CT | 90 | 100 | 72 | 104 | 60 |
| Truro, MA | 94 | 103 | 80 | 107 | 70 |
| Bar Harbor, ME | 93 | 101 | 79 | 104 | 70 |
| Nashua, NH | 85 | 92 | 72 | 94 | 62 |
| **Region 2 Sites** | | | | | |
| East Brunswick, NJ | 101 | 112 | 86 | 114 | 73 |
| Putnam Co., NY (New York City) | 92 | 103 | 74 | 106 | 61 |
| **Region 3 Sites** | | | | | |
| Davidsonville, MD | 102 | 114 | 84 | 119 | 73 |
| Bristol, PA (Philadelphia) | 105 | 116 | 89 | 119 | 77 |
| Pittsburgh, PA | 93 | 101 | 81 | 103 | 76 |
| Richmond, VA | 91 | 99 | 78 | 102 | 71 |
| **Region 4 Sites** | | | | | |
| Pensacola, FL | 84 | 91 | 78 | 93 | 73 |
| Atlanta, GA | 99 | 107 | 86 | 111 | 74 |
| Charlotte, NC | 102 | 115 | 85 | 120 | 73 |
| Knoxville, TN | 96 | 105 | 79 | 109 | 69 |
| **Region 5 Sites** | | | | | |
| Chicago, IL | 88 | 96 | 80 | 99 | 76 |
| Stillwater, MN (Minneapolis) | 73 | 78 | 66 | 81 | 61 |
| Cleveland, OH | 100 | 109 | 84 | 112 | 75 |
| Sheboygan, WI | 99 | 109 | 86 | 112 | 79 |
| **Region 6 Sites** | | | | | |
| Marion, AR (Memphis) | 94 | 103 | 79 | 106 | 71 |
| Baton Rouge, LA | 84 | 91 | 75 | 95 | 69 |
| Frisco, TX (Dallas) | 93 | 103 | 82 | 108 | 73 |
| Houston, TX | 108 | 117 | 95 | 123 | 87 |
| **Region 7 Sites** | | | | | |
| Kansas City, KS | 81 | 86 | 74 | 88 | 65 |
| St. Louis, MO | 91 | 98 | 78 | 101 | 71 |

Estimated 8-hour ozone design values increase with time for the without-CAAA scenario and decrease with time for the with-CAAA scenarios. For the with-CAAA scenarios, the number of sites for which attainment is not indicated is 19 for 2010 and 6 for 2020 (compared to 24 (all sites) for 2002). The results are qualitatively similar for all three metrics.

## Ozone Modeling Results for the Western U.S.

This section of the report provides an overview of the CMAQ modeling results for the 12-km western U.S. (WUS) modeling domain. These modeling results were generated for the assessment of ozone related health effects. The simulation period for the WUS domain is May through September.

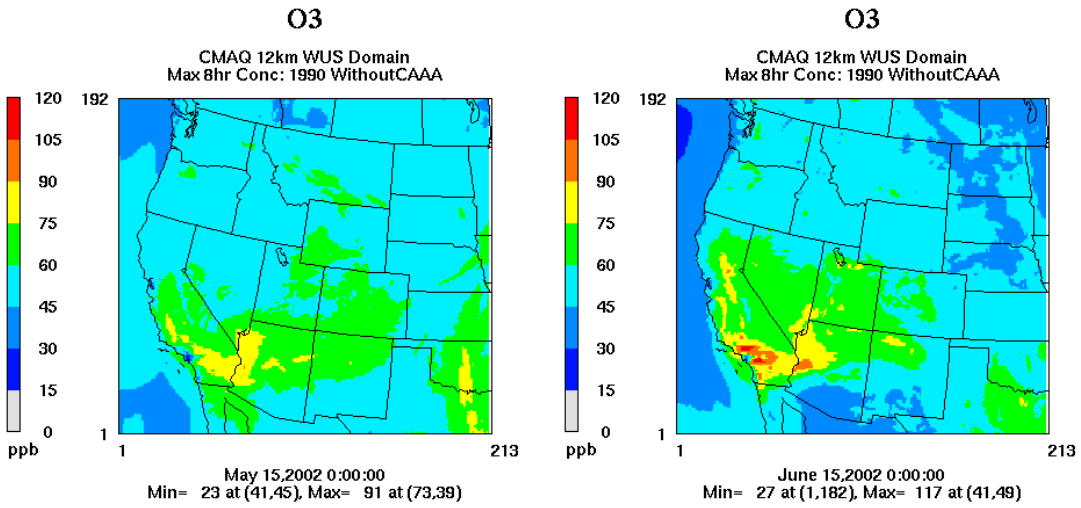
### 1990 Baseline Simulation

The 1990 scenario represents the base year for the CAAA and therefore this scenario does not include any CAAA measures.

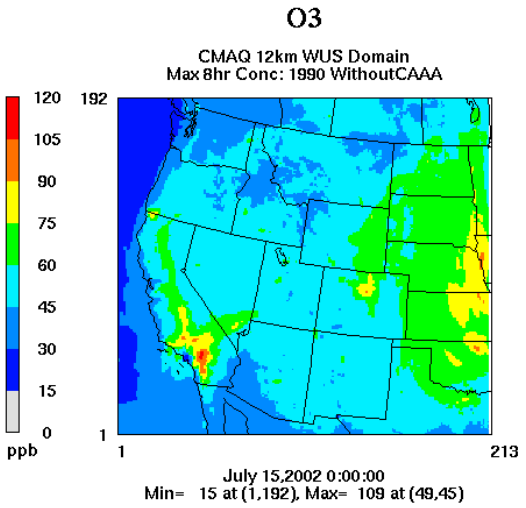
Figure IV-28 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 15th of May, June, July, August & September. The middle days of each month are used here to illustrate the month-to-month changes in ozone concentrations as well as a range of ozone concentration patterns.

**Figure IV-28. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for the 15th of May, June, July, August & September: 1990 Baseline Simulation.**

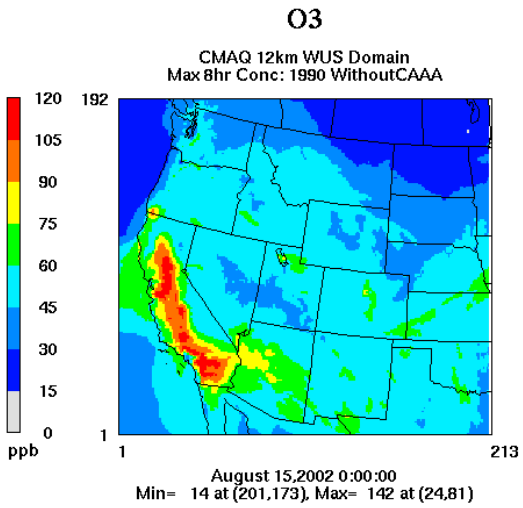
*(a) May* *(b) June*



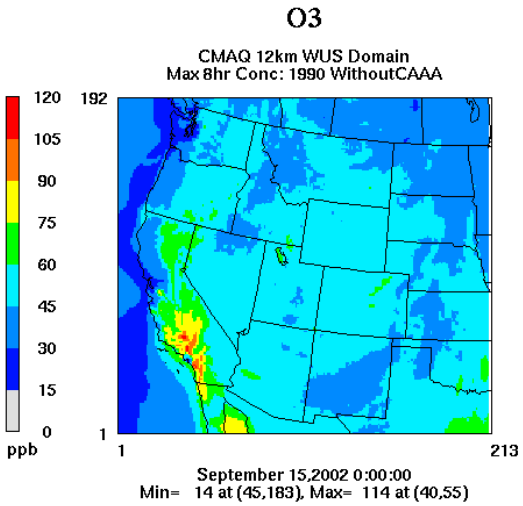
*(c) July*




*(d) August*




*(e) September*




All of the selected days show moderate to highest ozone concentrations over southern California. The area of high ozone extends into Arizona on June 15th and high ozone encompasses California's Central Valley on August 15th. There are also high ozone concentrations in the easternmost part of the domain on July 15th – matching the concentrations for the EUS domain on this day. For this subset of days, August 15th has the most widespread high ozone as well as the highest overall concentrations.

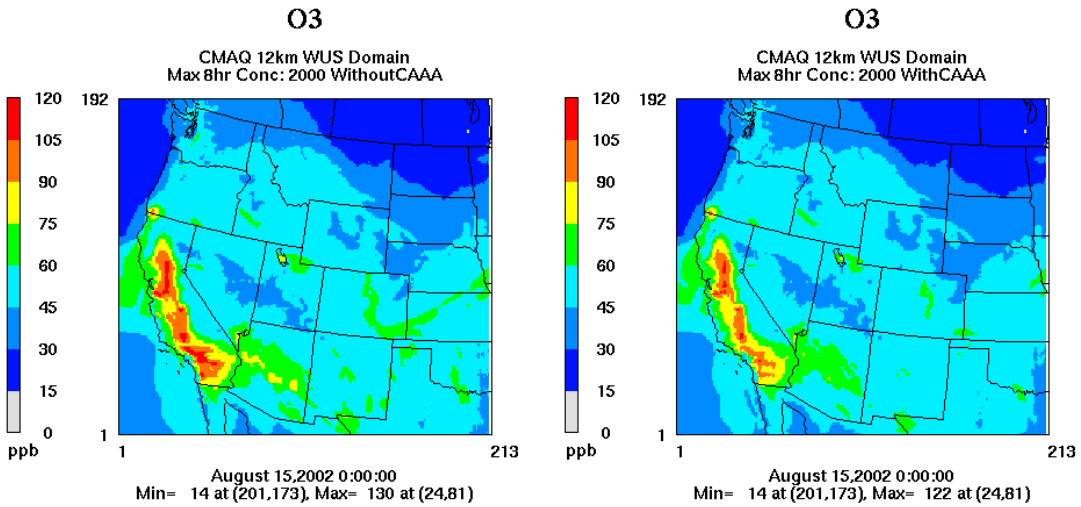
## Without-CAAA2000 and with-CAAA2000 Scenarios

Figure IV-29 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 2000 without-CAAA (Figure IV-29a) and 2000 with-CAAA (Figure IV-29b)

scenarios. The results for August 15th are shown. This day was selected as a representative high ozone day for comparison of the without- and with-CAAA scenarios.

**Figure IV-29. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2000 Scenarios.**

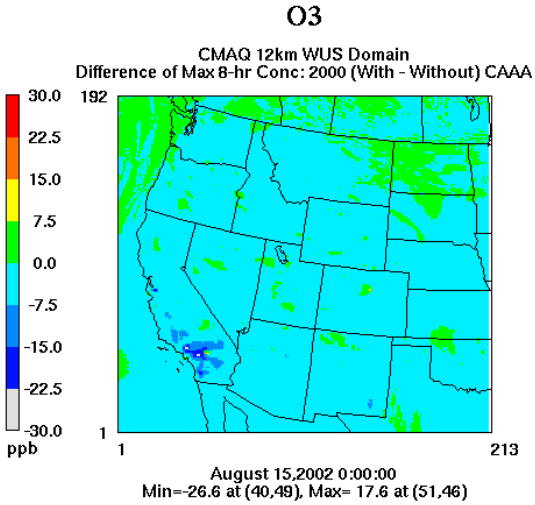
*(a) Without CAAA* *(b) With CAAA*




The 2000 without-CAAA scenario shows similar patterns throughout the WUS domain compared to 1990, but maximum simulated 8-hour ozone for 2000 is somewhat less in the Central Valley of California, the Los Angeles Basin, and parts of Arizona compared to 1990. This is due to estimated 7 percent reduction in total VOC emissions and 26 percent reduction in total $NO_x$ emissions in California, despite assumed growth. The major reductions are from the on-road mobile source sector, reflecting fleet turnover during these ten years and California vehicle emission standards, which are not related to the 1990 CAAA. The peak simulated 8-hour concentration for 15 August in the 2000 without-CAAA scenario is 130 ppb, while the peak value for the 1990 base case at this same location (Central California) is 142 ppb. The inclusion of emission reductions from the CAAA results in modest decreases in simulated maximum 8-hour ozone for this day.

Figure IV-30 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-30. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for the 15 August: 2000 With-CAAA Minus 2000 Without-CAAA Scenarios.**



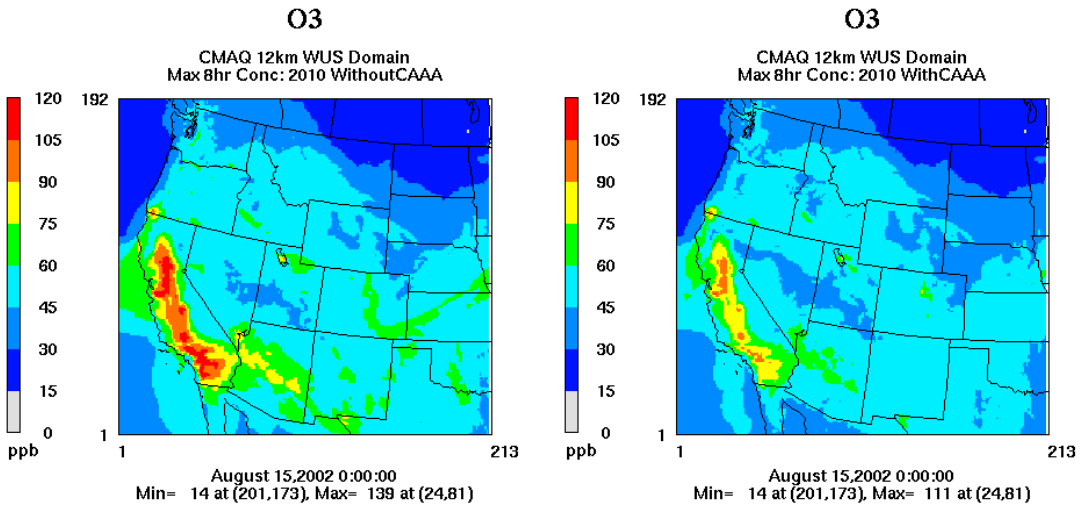

The inclusion of CAAA controls in 2000 results in modest reductions in simulated ozone concentrations throughout the WUS domain, with the largest reductions in 8-hour ozone occurring in the Los Angeles Basin.

## Without-CAAA2010 and with-CAAA2010 Scenarios

Figure IV-31 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for August 15th for the 2010 without-CAAA (Figure IV-31a) and 2010 with-CAAA (Figure IV-31b) scenarios.

**Figure IV-31. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2010 Scenarios.**

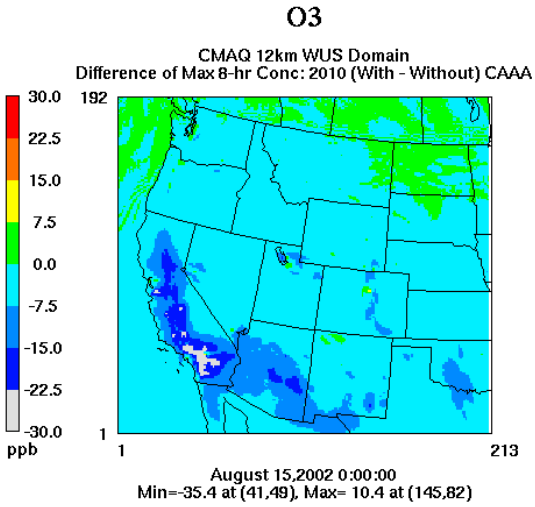
*(a) Without CAAA* *(b) With CAAA*



The results for the 2010 without-CAAA scenario for 15 August are quite similar in the extent and magnitude of simulated 8-hour ozone to the 1990 base case scenario, with high ozone confined to California's Central Valley, the Los Angeles Basin, and parts of central Arizona. The emissions reductions estimated in the 2000 without-CAAA case for California (from, for example, California vehicle emission standards) are somewhat outpaced by the assumed growth in population and motor vehicles, and the precursor emissions in 2010 are greater than 2000 levels for all source categories. The peak simulated 8-hour ozone concentration of 139 ppb, located in Central California, is comparable to the peak of 142 ppb in the 1990 base case.

Figure IV-32 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-32. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2010 With-CAAA Minus 2010 Without-CAAA Scenarios.**



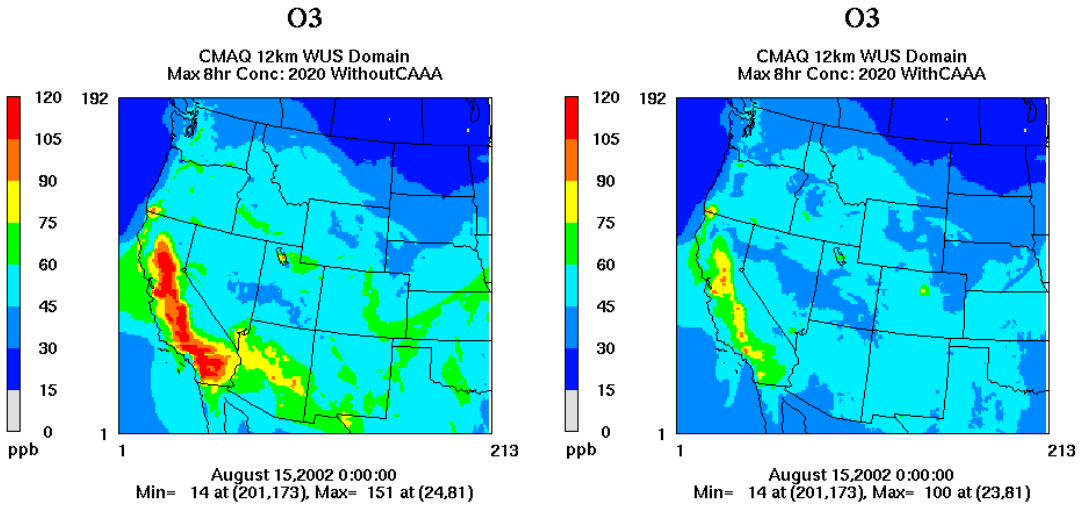

The inclusion of precursor emission reductions in the 2010 with-CAAA scenarios results in significant decreases in 8-hour ozone in the Los Angeles Basin, with smaller decreases shown in central Arizona and central California. The maximum decrease in 8-hour ozone is 35 ppb in the Los Angeles Basin when controls are included for 2010.

## Without-CAAA2020 and with-CAAA2020 Scenarios

Figure IV-33 displays simulated daily maximum 8-hour ozone concentration (ppb) for the WUS domain for the 15$^{th}$ of August for the 2020 without-CAAA (Figure IV-33a) and 2020 with-CAAA (Figure IV-33b) scenarios.

**Figure IV-33. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2020 Scenarios.**

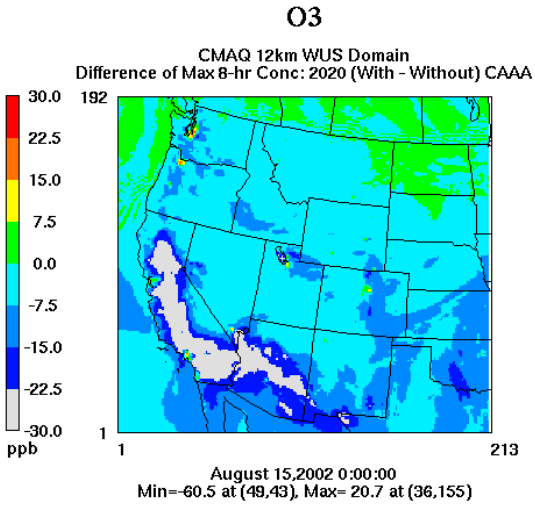
*(a) Without CAAA* *(b) With CAAA*




For the 2020 without-CAAA scenario, in which emissions are grown beyond 2010 levels, simulated 8-hour ozone increases substantially in California and Arizona. The peak simulated value for 2020 is 151 ppb, compared to a value of 139 ppb for 2010. The inclusion of controls in 2020 shows a large decrease in simulated 8-hour ozone in all areas, especially California and Arizona, resulting in no areas in Arizona showing concentrations over the current 8-hour ozone NAAQS of 75 ppb.

Figure IV-34 illustrates the differences in 8-hour ozone for this day between the two scenarios (with-CAAA minus without-CAAA).

**Figure IV-34. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for the WUS Domain for 15 August: 2020 With-CAAA Minus 2020 Without-CAAA Scenarios.**



The difference plot comparing the with- and without-CAAA control scenarios for 2020 shows the extent and magnitude of the differences in simulated 8-hour ozone concentrations, with the largest decrease of over 60 ppb for this day in Central California. In addition to decreases in simulated 8-hour ozone in California and Arizona, modest decreases are also seen in the central states (Texas, Oklahoma, and Nebraska).

## Summary of the Effects of the CAAA on Ozone Quality

Tabular summaries of the 12-km CMAQ ozone modeling results for selected subregions and monitoring sites are presented in this section.

The subregions follow the EPA region definitions. The EPA region definitions for all regions were provided earlier in this section. Only Regions 6 through 10 are partly or fully contained within the WUS domain and the definitions used for this analysis are as follows:

- **Region 6:** New Mexico, Oklahoma (partial), Texas (partial)
- **Region 7:** Iowa (partial), Kansas (partial), Nebraska
- **Region 8**: Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming
- **Region 9:** Arizona, California, Nevada
- **Region 10**: Idaho, Oregon, Washington

Ozone monitoring sites within each region were selected for a more detailed examination of the modeling results for specific urban areas. These were selected to represent approximately the same areas as the $PM_{2.5}$ monitoring sites. Preference was given to sites with high ozone design values, where possible. The WUS ozone monitoring sites are listed in Table IV-9. Note that both Region 7 sites are in the EUS domain and not in the WUS domain and are therefore not listed here.

**Table IV-9. Ozone Monitoring Sites Used in the Analysis of CMAQ Results for the WUS Modeling Domain for the 812 Modeling Study.**

| Region | Site Location |
|---|---|
| **Region 6** | Albuquerque, NM |
| | Frisco, TX (Dallas) |
| **Region 8** | Applewood, CO (Denver) |
| | Glacier National Park, MT |
| | Spanish Fork, UT (Provo-Orem) |
| **Region 9** | Phoenix, AR |
| | Cool, CA (Sacrament) |
| | Fresno, CA |
| | Bakersfield, CA |
| | Los Angeles, CA |
| **Region 10** | Boise, ID |
| | Seattle, WA |

Metrics used to summarize the modeling results for ozone include: peak simulated 8-hour ozone concentration, ozone exceedance exposure for a threshold of 75 ppb, and estimated design value. These metrics were defined previously in this report.

Table IV-10 lists the ozone exceedance exposure for each subregion and scenario. This metric is the amount by which the simulated ozone concentration exceeds 75 ppb, summed over all grid cells (within the selected area) and all days.

**Table IV-10. Ozone Exceedance Exposure Based on 75 ppb for the WUS Domain and all Section 812 Scenarios. Units are ppb * grid cell * days.**

| Region | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| Region 6 | 448,398 | 399,598 | 134,684 | 591,194 | 15,963 | 1,118,006 | 1,644 |
| Region 7 | 133,126 | 138,395 | 28,456 | 210,848 | 2,032 | 409,052 | 75 |
| Region 8 | 90,550 | 111,953 | 47,499 | 159,051 | 22,390 | 302,551 | 7,622 |
| Region 9 | 5,757,786 | 3,533,353 | 1,628,242 | 5,339,838 | 597,833 | 8,932,696 | 189,229 |
| Region 10 | 24,341 | 24,540 | 20,281 | 32,645 | 15,170 | 50,823 | 12,515 |

This is an interesting summary because it includes results for a variety of different geographic areas with a wide range of baseline ozone exceedance exposure values and corresponding ozone concentrations. For the without-CAAA scenarios, a mix of increases and decreases between 1990 and 2000 (depending on the region) is followed by a steady increase with time. The largest increases tend to occur between 2010 and 2020, where in some cases ozone exceedance exposure nearly doubles. Ozone exceedance exposure consistently decreases with time for the with-CAAA scenarios. There is a very large reduction in this metric for Region 9 (which includes California). For most areas, only a small fraction of grid cells and days have simulated 8-hour ozone concentrations greater than 75 ppb by 2020.

Table IV-11 lists the peak simulated 8-hour ozone concentration for each WUS monitoring site and scenario.

**Table IV-11. Simulated Maximum 8-Hour Ozone Concentration (ppb) for Selected Monitoring Sites in the WUS Domain and all Section 812 Scenarios.**

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| **Region 6 Sites** | | | | | | | |
| Albuquerque, NM | 80.8 | 79.6 | 74.8 | 82.9 | 68.8 | 88.0 | 64.6 |
| Frisco, TX (Dallas) | 102.9 | 104.1 | 97.1 | 107.9 | 84.7 | 113.9 | 73.8 |
| **Region 8 Sites** | | | | | | | |
| Applewood, CO (Denver) | 108.8 | 104.6 | 106.5 | 109.1 | 99.9 | 113.9 | 92.6 |
| Glacier National Park, MT | 58.9 | 58.8 | 58.5 | 58.8 | 58.2 | 58.5 | 57.7 |
| Spanish Fork, UT (Provo-Orem) | 82.9 | 77.8 | 77.3 | 80.3 | 75.3 | 83.7 | 70.5 |

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| **Region 9 Sites** | | | | | | | |
| Phoenix, AZ | 100.7 | 97.5 | 93.0 | 101.3 | 87.6 | 104.6 | 79.7 |
| Cool, CA (Sacramento) | 119.9 | 110.7 | 107.2 | 118.0 | 98.8 | 127.8 | 90.1 |
| Fresno, CA | 111.5 | 101.9 | 100.2 | 108.6 | 91.5 | 116.4 | 87.1 |
| Bakersfield, CA | 101.6 | 97.9 | 93.0 | 101.7 | 86.4 | 108.4 | 82.3 |
| Glendora, CA (Los Angeles) | 111.0 | 131.3 | 103.7 | 139.4 | 100.5 | 156.5 | 96.3 |
| **Region 10 Sites** | | | | | | | |
| Boise, ID | 77.5 | 79.6 | 79.0 | 82.2 | 76.5 | 84.6 | 76.2 |
| Seattle, WA | 70.2 | 66.9 | 62.6 | 69.2 | 60.3 | 71.7 | 60.3 |

Following a mix of increases and decreases in the simulated maximum 8-hour ozone concentrations between 1990 and 2000, the values generally increase with time for the without-CAAA scenarios and decrease with time for the with-CAAA scenarios.

Table IV-12 presents the estimated future-year 8-hour ozone design values for each monitoring site and scenario. The future-year design values were estimated based on a 2002 baseline (observation-based) design value. Site-specific model-derived relative reduction factors were applied to the baseline design values in order to estimate the future-year design values. This procedure is described in detail in EPA's modeling guidance document (EPA, 2007). Note that a future-year design value less than or equal to 75 ppb is an indicator of future-year attainment.

**Table IV-12. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for Selected Monitoring Sites in the WUS Domain and the Future-Year Section 812 Scenarios.**

| | 2002 DV | 2010 w/o CAAA | 2010 w/CAAA | 2020 w/o CAAA | 2020 w/CAAA |
|---|---|---|---|---|---|
| **Region 6 Sites** | | | | | |
| Albuquerque, NM | 70 | 75 | 65 | 77 | 60 |
| Frisco, TX (Dallas) | 93 | 102 | 81 | 107 | 73 |
| **Region 8 Sites** | | | | | |
| Applewood, CO (Denver) | 82 | 83 | 79 | 86 | 76 |
| Glacier National Park, MT | 52 | 52 | 51 | 52 | 51 |
| Spanish Fork, UT (Provo-Orem) | 75 | 78 | 71 | 79 | 66 |
| **Region 9 Sites** | | | | | |
| Phoenix, AZ | 86 | 93 | 82 | 95 | 75 |
| Cool, CA (Sacramento) | 106 | 116 | 98 | 122 | 91 |
| Fresno, CA | 115 | 124 | 106 | 132 | 102 |
| Bakersfield, CA | 101 | 109 | 94 | 116 | 90 |
| Glendora, CA (Los Angeles) | 111 | 109 | 94 | 116 | 90 |
| **Region 10 Sites** | | | | | |
| Boise, ID | 78 | 81 | 75 | 84 | 74 |
| Seattle, WA | 68 | 71 | 66 | 72 | 63 |

Estimated 8-hour ozone design values tend to increase with time for the without-CAAA scenario and decrease with time for the with-CAAA scenarios. Sites with low base design values show less of a response either way, compared to sites with high base design values. Glacier National Park shows little change, likely due to the isolated location of the monitoring site. For the with-CAAA scenarios, the number of sites for which attainment is not indicated is 8 for 2010 and 6 for 2020 (compared to 9 for 2002). The results are qualitatively similar for all three metrics.

The Frisco, TX (Dallas) monitoring site appears in both summary tables, for the EUS and WUS domain and it interesting to compare the results for the two modeling domains. The maximum 8-hour simulated concentrations for this site are show in Table IV-13a and the estimated design values are given in Table IV-13b.

**Table IV-13a. Simulated Maximum 8-Hour Ozone Concentration (ppb) for the Frisco, TX (Dallas) Monitoring Site for all Section 812 Scenarios.**

| | 1990 Baseline | 2000 w/o CAAA | 2000 w/ CAAA | 2010 w/o CAAA | 2010 w/ CAAA | 2020 w/o CAAA | 2020 w/ CAAA |
|---|---|---|---|---|---|---|---|
| EUS Simulation | 95.0 | 94.9 | 86.8 | 96.7 | 77.7 | 100.0 | 71.4 |
| WUS Simulation | 102.9 | 104.1 | 97.1 | 107.9 | 84.7 | 113.9 | 73.8 |

**Table IV-13b. Estimated Future-Year 8-Hour Ozone Design Value (ppb) for the Frisco, TX (Dallas) Monitoring Site for the Future-Year Section 812 Scenarios.**

| | 2002 DV | 2010 w/o CAAA | 2010 w/CAAA | 2020 w/o CAAA | 2020 w/CAAA |
|---|---|---|---|---|---|
| EUS Simulation | 93 | 103 | 82 | 108 | 73 |
| WUS Simulation | 93 | 102 | 81 | 107 | 73 |

The simulated concentrations are higher for the WUS domain, but the estimated design values are very similar for both grids. This indicates that model performance is different for the two grids in the overlap area, but that the response of the model to the emissions changes is about the same.

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# Section V
# Discussion of Attributes and Limitations

Unlike the air quality modeling conducted over a decade ago for the first Section 812 prospective analysis, which used two different models for ozone and particulate matter, the modeling conducted for the second prospective analysis utilized EPA's Community Multiscale Air Quality (CMAQ) model, a "one-atmosphere" model that simulates the chemical formation, transport, and deposition of ozone and particulate matter together in one comprehensive system. (The use of a model such as CMAQ was one of the recommendations that came out of the first prospective modeling analysis.) The use of a comprehensive air quality modeling system provides a consistent platform for evaluating the expected responses to changes in precursor emissions.

The CMAQ grid resolution and the annual and seasonal simulation periods used for this study are consistent with current EPA modeling guidance. A 36-km resolution continental-scale grid (CONUS) was used to simulate fine particulates ($PM_{2.5}$) and visibility. The 36-km simulations were run for an annual simulation period. In addition, two 12-km resolution grids (EUS – Eastern U.S. and WUS – Western U.S.) were used to simulate ozone concentrations (with higher resolution). The 12-km simulations were run for a five-month simulation period encompassing the ozone season.

The air quality modeling analysis conducted for the second Section 812 prospective study used national-scale modeling databases originally prepared by EPA for use in other recent modeling exercises conducted to support national rulemaking, including the latest available meteorological and other input databases (for 2002). Given that the modeling databases were originally prepared and utilized by EPA in other analyses, a comprehensive performance evaluation was not undertaken as part of this Section 812 prospective analysis. However, there still could exist various biases in the simulated concentration fields due to the inaccurate depiction of the meteorological fields or errors in the emission inventory inputs. In addition, biases or uncertainties could be manifested in the simulated concentration fields due to the use of the 36- and 12-km resolution grids, which might not be sufficiently detailed to resolve certain sub-grid scale processes in portions of the modeling domain. All air quality modeling exercises are affected by inherent uncertainties in model formulation, meteorological inputs, and emission inventory estimates. Nevertheless, the modeling was conducted following current EPA guidelines and consistent with EPA approaches/practice for similar national-scale modeling exercises.

For the future-year analysis for 2010 and 2020, the air quality forecasts provided by CMAQ are only as good as the future-year emission estimates. Although much effort was undertaken to provide accurate estimates of expected future growth in population and economic and industrial activity, such estimates still contain uncertainties due to potential unknown social, political, and/or economic factors that may affect growth/activity and resulting emissions in the future. In addition, the planned emission reductions by various source sectors due to the CAAA-mandated provisions may not occur with the expected degree of emission-reduction effectiveness or on the

schedule assumed in this modeling analysis. Also, it is generally accepted that the farther out the forecast (e.g., 2020), the more uncertain are the future-year estimates.

It is also important to note that while this study was being conducted, two of EPA's major emission reduction rules affecting future controls on EGU $SO_2$ and $NO_x$ emissions for 2010 and 2020, namely the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR), were vacated by U.S. Court of Appeals for the District of Columbia. The CAIR was vacated on 11 July 2008 and the CAMR was vacated on 8 February 2008. The expected emissions reductions from the original CAIR and CAMR provisions were included in the modeling analysis presented in this report. Unless EPA quickly develops and adopts new rules that will be acceptable to the Court, the expected emissions reductions from CAIR and CAMR assumed in the second prospective modeling analysis will likely not be realized by 2010. This will reduce the accuracy of the future-year emissions projections and simulated ozone and PM concentrations for 2010 primarily in the eastern portion of the U.S. Depending on the final level of mandated reductions for EGUs and the schedule for such reductions contained in revised/updated rules, the results for 2020 presented herein are also somewhat uncertain.

# Section VI
# Summary and Recommendations for Further Research

For the second Section 812 prospective modeling analysis, the CMAQ air quality model was applied to estimate the effects of implementing the CAA measures on future-year ambient air quality. The CMAQ model was applied for seven core CAAA scenarios including the 1990 without-CAAA, 2000 without-CAAA, 2010 without-CAAA, 2020 without-CAAA, 2000 with-CAAA, 2010 with-CAAA and 2020 with-CAAA scenarios.

Emission inventories were developed for each of the scenario years. Emissions for the historical years (1990 and 2000) were based on the best available emission inventories for these years. Projection to the future years was based on economic growth projections, future-year control requirements (for attainment of National Ambient Air Quality Standards (NAAQS)), and control efficiencies. Different assumptions were applied for the with- and without-CAAA scenarios resulting in a different future-year emissions pathway for each scenario.

The model-ready emission inventories for each scenario and year were then used to obtain base- and future-year estimates of the key criteria pollutants, as well as many other species. For fine particulate matter ($PM_{2.5}$) and related species, the CMAQ model was applied for an annual simulation period (January through December). A 36-km resolution modeling domain that encompasses the contiguous 48 states was used for the annual modeling. For ozone and related species, the CMAQ model was applied for a five-month simulation period that captures the key ozone-season months of May through September. Two 12-km resolution modeling domains (that when combined cover the contiguous 48 U.S. states) were used for the ozone-season modeling. Altogether, model-ready emission inventories were prepared and the CMAQ model was applied for a total of 21 simulations (comprising seven core scenarios and three modeling domains). Simulated concentrations of ozone, $PM_{2.5}$, and $PM_{2.5}$ species and deposition of sulfur, nitrogen and other species provide the basis for the calculation of health and ecological benefits of the CAA.

Use of the CMAQ model provided the opportunity to simulate the interactions of gaseous and particulate precursors that lead to the formation, transport, and deposition of both ozone and particulate matter in the atmosphere. The inclusion of emission reductions for the future years due to CAAA controls resulted in substantial reductions in simulated ozone and PM throughout the U.S. Without such controls, many areas of the country would most likely fall into or continue to be in violation of the existing National Ambient Air Quality Standards (NAAQS) for ozone and $PM_{2.5}$. This would also affect progress towards improving regional haze and reaching the longer-term visibility improvement goals throughout the country. With the expected reductions due to CAA measures, the simulations indicate that most areas of the country (with a few exceptions) will be in compliance of the ozone and $PM_{2.5}$ NAAQS by 2020.

For this analysis, CMAQ's Particle and Precursor Tagging Methodology (PPTM) was also utilized as a quality-assurance tool to evaluate the contribution of source-category emissions on simulated

$PM_{2.5}$ for 2010. The use of PPTM provided additional information regarding which source categories were contributing most to the simulated and PM concentration fields throughout the US. This information can be used to refine the benefits analysis because contribution information (and resulting effectiveness) can now be evaluated and quantified by source category and control program, rather than just lumping all of the controls together and assuming equal effectiveness.

The following is a set of recommendations aimed at extending and improving the air quality modeling analysis to better support the overall Section 812 prospective analysis:

- Conduct additional modeling to evaluate any changes resulting from the re-issuance of the CAIR or CAMR legislation that would affect the expected magnitude and timing of future emission reductions on EGU sources throughout the U.S.
- Continue to utilize the most up-to-date national emission inventory estimates for all source sectors, taking advantage of updates in population & activity levels, revisions in emission factors, and new information submitted to EPA by states.
- Conduct additional modeling using meteorological inputs from a different base year (e.g., 2005) to test the robustness and sensitivity of the results and conclusions for another set of annual meteorological conditions.
- Extend the use of PPTM and OPTM techniques to further evaluate contributions to simulated PM and ozone in an effort to better quantify control effectiveness (and resulting benefits/costs) by source category, pollutant, and/or geographic area.
- Extend the analysis to include assessments of mercury deposition throughout the U.S. and the resulting effects and benefits of changes to watersheds from CAAA controls
- Use a modified set of meteorological inputs for 2020 that emulate/simulate the expected changes in meteorological conditions due to global warming/climate change to evaluate how emission reduction effectiveness changes in the future under these conditions.

# Section VII
# References


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